NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

Baseline Vibration Measurements of Remotely Piloted Helicopters for Higher Harmonic Control Research

by

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December, 1991

Thesis Advisor: E. Roberts Wood

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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Postgraduate School 6b. OFFICE SYMBOL (If applicable) AA	7a. NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000	7b. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS Program Element No / Project No / Task No / Work Unit Accession Number

11. TITLE (Include Security Classification)
Baseline Vibration Measurements of Remotely Piloted Helicopters for Higher Harmonic Control Research (U)

12. PERSONAL AUTHOR(S) Ransford, Kevin M.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (year, month, day)	15. PAGE COUNT
Master's Thesis	From To	December 1991	71

16. SUPPLEMENTARY NOTATION
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17. COSATI CODES			18. SUBJECT TERMS (continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUBGROUP	HHC, RPH, Vibrations, Flight Tests, Ground Tests

19. ABSTRACT (continue on reverse if necessary and identify by block number)

The Department of Aeronautics and Astronautics at the Naval Postgraduate School (NPS) is conducting a research program in the methods of higher harmonic control (HHC) for reduction of helicopter vibrations. The program at NPS uses remotely piloted helicopters (RPH) to study HHC effects on vibration and blade load reduction. The scope of this masters thesis was to measure the baseline vibration profile of the RPH test vehicles prior to the installation of a HHC system. This goal was met by the development of a data instrumentation and recording system and by conducting a ground and flight test program for the RPH test vehicles. From the results of these tests it was concluded that: a) the data instrumentation and recording system was of sufficient sensitivity to detect vibrations experienced within the RPH airframe, and, b) the RPH exhibited a vibration profile similar to that of a full scale helicopter. It is recommended that a HHC system be designed, fabricated, and installed on the Pacific RPV Co. 'Bruiser' so that the effects of HHC on helicopter performance may be evaluated.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT [X] UNCLASSIFIED/UNLIMITED [ ] SAME AS REPORT [ ] DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Professor E. Roberts Wood	22b. TELEPHONE (Include Area code) (408) 646-2897	22c. OFFICE SYMBOL AA/Wd

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

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Baseline Vibration Measurements of Remotely Piloted Helicopters For Higher Harmonic Control Research

by

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Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN ENGINEERING SCIENCE (AERONAUTICS)

from the

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

The Department of Aeronautics and Astronautics at the Naval Postgraduate School (NPS) is conducting a research program in methods of higher harmonic control (HHC) for reduction of helicopter vibrations. The program at NPS uses remotely piloted helicopters (RPH) to study HHC effects on vibration and blade load reduction. The scope of this master's thesis was to measure the baseline vibration profile of the RPH test vehicles prior to the installation of a HHC system. This goal was met by the development of a data instrumentation and recording system and by conducting a ground and flight test program for the RPH test vehicles. From the results of these tests it was concluded that: a) the data instrumentation and recording system was of sufficient sensitivity to detect vibrations experienced within the RPH airframe; and b) the RPH exhibited a vibration profile similar to that of a full scale helicopter. It is recommended that a HHC system be designed, fabricated, and installed on the RPH so that the effects of HHC on helicopter performance may be evaluated.

TABLE OF CONTENTS

I. INTRODUCTION

Analysis and control of helicopter vibrations is an area of vital concern to the helicopter designer, operator, and mechanic. Excessive vibration levels are detrimental to the helicopter airframe and its components, and can also lead to the early onset of flight crew fatigue. Therefore, reduction of vibration levels to a minimum acceptable value remains of prime importance. Fortunately, continued research into methods for the reduction of vibrations has produced a gradual reduction in vibration levels [Figure 1, (Ref 1)].

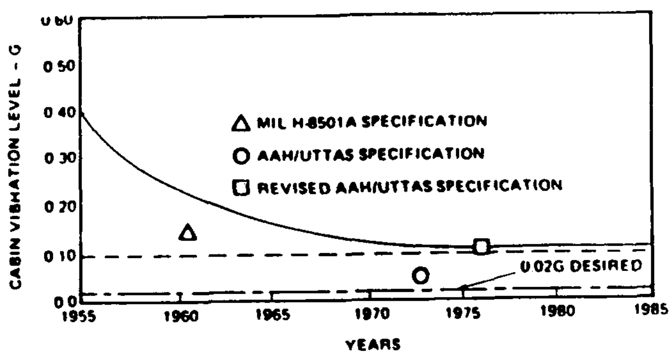


Figure 1. The Trend of Helicopter Vibration Levels

Methods for reduction of helicopter vibrations include both active and passive measures. Passive measures include mechanical vibration absorbers and isolators. Active measures include individual blade control (IBC) [Ref 2.] and higher harmonic control (HHC). As shown in Figure 1, the level of

vibration reduction that may be realized by passive methods has reached its maximum potential. Thus, an active means of reducing this level of vibration now appears to provide the best possible solution.

Research in the application of HHC for vibration control has been conducted since the early 1960's to investigate its effect on both vibration and blade-load reduction. References 3 through 9 summarize the results of this research. Reference 3 is noteworthy in that it was the only actual flight test program using the HHC concept until the 1980's.

Reference 1 reported on development and flight tests of HHC by Hughes Helicopters, Inc. (now McDonnell Douglas Helicopter Co.) under a joint U.S. Army/National Aeronautics and Space Administration (NASA) program using an OH-6A helicopter during 1982-83. Flight test results presented in this study showed that the HHC system provided a significant reduction in helicopter vibrations without penalties in blade loads or aircraft performance. Further analysis of these HHC flight test results showed a possible performance increase for the helicopter using HHC. This increase was characterized by a twenty per-cent (20%) reduction in required main rotor shaft torque [Ref. 10]. However, the scope of the HHC test program [Ref. 1] and funding limitations prevented additional flight testing and evaluation of the effects of HHC on helicopter performance.

Thus, important questions regarding the effects of HHC on helicopter performance remain unanswered. How will it change power available? That is, does minimum power occur at the same phase as minimum vibration? At what airspeeds will performance show the greatest increase (or decrease)? What is the effect of HHC on fuel consumption? It is with these questions in mind that the HHC research program at the Naval Postgraduate School (NPS) was established.

This NPS HHC program has been conducted by master's level thesis students with the intent of developing an active flight test program. This flight test program utilizes remotely piloted helicopters (RPH) as the primary flight test vehicles. Previous research efforts at NPS [Ref's. 11 through 15] focused primarily on the procurement, construction, and calibration of the RPH, and on the establishment of a vertical flight test capability at the NPS Unmanned Air Vehicle (UAV) Flight Research Laboratory. The scope of this masters thesis is to conduct an initial ground and flight test investigation of the RPH test vehicles vibration spectrum, prior to modification of the RPH to the HHC system.

II. FUNDAMENTALS OF HIGHER HARMONIC CONTROL

Higher harmonic control of helicopter vibrations is a method by which an active control system is used to control and reduce the level of helicopter vibrations. The vibrations of greatest magnitude result from aerodynamic loads acting on the main rotor system. Dynamic coupling of these loads between the rotor system and the airframe results in a measurable vibration profile for the aircraft. Other sources of vibrations include the engine and tail rotor, which provide excitation at a reduced level compared with those imparted to the airframe by the main rotor system.

Reduction of the level of vibrations is accomplished using HHC by measuring the vibrations which are transmitted to the airframe, and then imparting a motion back to the main rotor system (blade pitch) at a frequency which will reduce or cancel the dominant vibration frequency. For a four-bladed helicopter, this method is normally applied as follows: Tri-axial accelerometers located at the pilot's seat in the airframe sense vertical, lateral, and longitudinal vibrations. These vibrations are converted to electrical signals and are then routed to an electronic processing unit. The processing unit analyzes the accelerometer signals and determines the level of blade feathering required to cancel the vibration. A superimposed 4/rev. swashplate motion is

applied to collective and cyclic control inputs. Perturbing the stationary swashplate at 4/rev. both collectively and in pitch and roll results in third, fourth, and fifth harmonic blade feathering (typically less than one degree) in the rotating system. This feathering action results in reduced excitation from the rotor system, which acts as a filter and transmits the corresponding lower vibration levels to the airframe. Pitch, roll, and collective motion of the stationary swashplate at this 4/rev. frequency is provided by electro-hydraulic or electronic high frequency servo-actuators. Depending on system design, HHC may be operated in the open- or closed-loop mode. [Ref. 1] However, HHC research at NPS will be conducted initially in the open-loop format.

III. DESCRIPTION OF RPH TEST VEHICLES

Development of the ground and flight test program at NPS (using the RPH test vehicles) has been based upon a systematic, gradual build-up of instrumentation, testing milestones, and pilot proficiency prior to installation and flight test of a RPH with HHC. This test program was designed so that initial instrumentation development, data collection techniques, and pilot training could all be conducted on a RPH that was easy and inexpensive to fly, modify, and maintain. Pilot training was considered of paramount importance, as it placed a severe limitation on data collection and analysis in previous thesis studies [Ref. 15]. These considerations led to the procurement of two RPH test vehicles. RPH test vehicles were chosen for this research effort because they offer a means of investigating the properties of HHC without the cost of a full scale flight test program. In addition, the RPH uses control systems and main/tail rotor blade airfoil sections similar to a full scale helicopter. Thus, it is expected that the RPH test vehicles would yield research results which may be useful to the full scale helicopter designer.

The first of these test vehicles, the GMP **Legend**, is a two-bladed aircraft with a stabilizing flybar, a two-bladed tail rotor, and a .61 cubic inch engine. The second test

vehicle, the Pacific RPV **Bruiser** is a four-bladed aircraft with a four-bladed tail rotor, and a four horsepower engine. For this test program, the **Legend** was used as the instrumentation development and pilot training aircraft, and the **Bruiser** was used for initial ground-based vibration measurement studies prior to the installation of the HHC system. A primary factor in the selection of the **Bruiser** for HHC work was that it had a four-bladed rotor. Since (n-1), n, and (n+1) per rev. frequencies are involved, the (n-1) component for a two-bladed rotor (1/rev.) couples into the output of the primary control system, which is undesirable. This problem is eliminated with the four-bladed rotor system. These aircraft are described more fully in following paragraphs.

A. THE GMP LEGEND

The GMP **Legend**, as noted previously, is a two-bladed flybar stabilized RPH. This aircraft was chosen as the initial development aircraft because it allowed the test team to develop test methods, instrumentation, and data collection techniques (with the added capability of being an excellent training aircraft for the novice RPH pilot) prior to operating the more difficult-to-fly **Bruiser**. The ease in maintenance and the availability of spare parts were also fundamental considerations in the choice of the **Legend** for the initial stages of the test program. The **Legend** is presented Figure 2.

Control of the **Legend** is accomplished using a Futaba Corp. Model F995HP nine channel transmitter, which operates using a pulse code modulation (PCM) transmission technique. A radio receiver, rate gyros, and control servos mounted on the RPH, complete the system. An added advantage of this transmitter system is that it is similar to the system used to control the **Bruiser** RPH. Table I provides additional specifications of the GMP **Legend**.

Figure 2. The GMP Legend

TABLE I. LEGEND SPECIFICATIONS

Main Rotor Diameter	58"
Number of Rotor Blades	2
Tail Rotor Diameter	10"
Length	51"
Weight	8.8 lbs
Payload	10 lbs
Engine	.61 cu. in.
Operating RPM (Main Rotor)	1500 - 1700 RPM
Engine to Main Rotor Gearing Ratio	8.6:1
Main Rotor to Tail Rotor Gearing Ratio	4.75:1

Engine, main rotor, and tail rotor excitation frequencies and gearing ratios provide key information for the vibration researcher because they characterize the primary vibration frequencies transmitted to the airframe. These are the frequencies of interest for HHC, so that it can be effective in eliminating or reducing vibration excitation at these frequencies. For a RPH like the two-bladed **Legend**, the troublesome frequencies will occur at main rotor frequencies of 1/rev., 2/rev., 4/rev., and harmonics thereof. Engine and tail rotor primary frequencies and harmonics will also be present. It should be noted that these frequencies will be valid for only one main rotor operating RPM. In other words, a change in operating RPM will result in a change in the primary frequencies and their harmonics. Table II provides a list of characteristic frequencies for operation at 1502 RPM.

TABLE II. GMP LEGEND CHARACTERISTIC FREQUENCIES (MAIN ROTOR OPERATING 1502 RPM)

Main Rotor n/rev.	Frequency
1/rev.	25 Hz.
2/rev.	50 Hz.
4/rev.	100 Hz.
6/rev.	150 Hz.
8/rev.	200 Hz.
Tail Rotor n/rev.	**Frequency**
1/rev.	118 Hz.
2/rev.	237 Hz.
4/rev.	475 Hz.
Engine n/rev.	**Frequency**
1/rev.	215 Hz.
2/rev.	460 Hz.

B. THE PACIFIC RPV CO. BRUISER

The Pacific RPV Co. **Bruiser** is a four-bladed helicopter that was designed and built by the Pacific RPV Co., of Startup, Washington. This RPV was procured for use as the HHC test vehicle. Original design of this helicopter was for the purposes of aerial spraying, photography, and electronic countermeasures (ECM). The **Bruiser** is equipped with a four-bladed, fully-articulated rotor head, with a four-bladed tail rotor. Like the GMP **Legend**, the **Bruiser** utilizes a nine-channel PCM transceiver system (using a Futaba Corp. FP-9VHP transmitter) for operation of all flight control surfaces and engine throttle movements. Electronic servos, controlled by the airborne receiver (a Futaba Corp. FP-R129DP), operate tail rotor, collective, and collective/cyclic pitch

mechanisms. The **Bruiser** is powered by a Super Tartan T77i two-cylinder, two-cycle, air-cooled engine. This engine will produce a maximum four brake horsepower (BHP) at 8,800 RPM, but is typically operated at approximately 7,000 RPM. The **Bruiser** is depicted in Figure 3. Additional specifications of the **Bruiser** are contained in Table III.

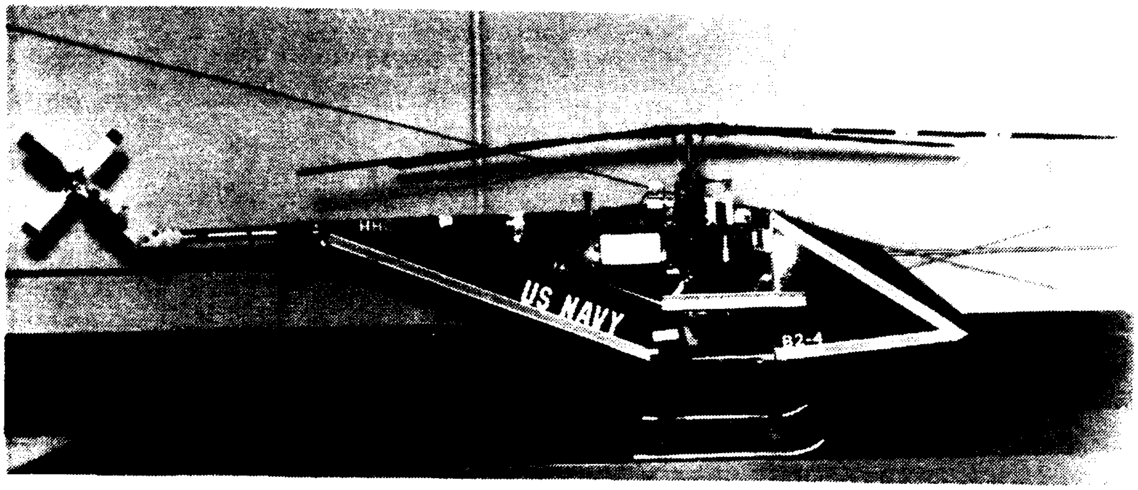


Figure 3. The Pacific RPV Co. Bruiser

TABLE III. THE PACIFIC RPV CO. BRUISER

Max. Forward Speed	50 KTS
Number of Rotor Blades	4
Rotor Diameter	78 in.
Tail Rotor Diameter	13 in.
Empty Weight	18 lbs.
Gross Weight	40 lbs.
Main Rotor Normal Operating RPM	1175 RPM
Engine to Main Rotor Gearing Ratio	8:1
Main Rotor to Tail Rotor Gearing Ratio	6:1

As with the GMP **Legend**, engine, main rotor, and tail rotor gearing ratios will be used to identify primary frequencies and harmonics of the rotating components when the **Bruiser** is operated at a specific rotor RPM. Table IV lists the characteristic values of these frequencies for operation at 1175 RPM, which is normal operating speed.

TABLE IV. PACIFIC RPV CO. BRUISER CHARACTERISTIC FREQUENCIES (MAIN ROTOR OPERATING 1175 RPM)

Main Rotor n/rev.	Frequency
1/rev.	19 Hz.
2/rev.	39 Hz.
4/rev.	78 Hz.
6/rev.	117 Hz.
8/rev.	156 Hz.
Tail Rotor n/rev.	**Frequency**
1/rev.	117 Hz.
2/rev.	234 Hz.
Engine n/rev.	**Frequency**
1/rev.	156 Hz.
2/rev.	313 Hz.

It should be noted that main rotor 6/rev. and tail rotor 1/rev. are the same frequency of 117 Hz. This condition also exists for main rotor 8/rev. and engine 1/rev. While this condition will not result in unusual vibrations or operation of the RPH, it will make contributions of the individual components of the tail rotor 1/rev. and engine 1/rev. vibration amplitudes much more difficult to separate and analyze.

IV. DESCRIPTION OF TEST INSTRUMENTATION

Analysis and recording of helicopter vibrations on a full scale helicopter is normally performed using selected accelerometers and monitoring equipment. This equipment may include an oscilloscope, a spectrum-type signal analyzer, or a direct plotting device such as the Chadwick Helmuth Corp. Vibration Test Set. Each of these equipments was considered during development of a data measuring and recording system for the RPH test vehicles. As with a full scale test program, size, weight, and power constraints were primary factors in considering what system or combinations of systems would best serve the test program needs. In addition, the system chosen must be sensitive enough to detect vibrations at various frequencies from 1 to 1000 Hz., at amplitudes much less than those encountered with a full scale helicopter. Review of the available instrumentation options led to the choice of a spectrum analyzer which could both store data for later retrieval and which would interface with a plotter/printer without additional hardware. A tri-axial mount with highly sensitive accelerometers was procured for mounting on the RPH. Individual components and a system description is provided in greater detail in the following paragraphs.

A. THE SCIENTIFIC-ATLANTA SD380 SIGNAL ANALYZER

The Scientific-Atlanta SD380 Signal Analyzer is a four-channel spectrum analyzer that is designed to provide frequency domain display of various electronic signals. Up to four channels of input data may be displayed in either a logarithmic, linear, or waterfall format. Cursor tracking, statistical parameters, and text features allow for complete data analysis without additional microcomputer operations. Display data may be stored on a 3.5 in. floppy disk via the SD380's disk drive, and, plotting/printing operations may be performed via the installed IEEE 488 data bus. These latter two attributes were considered to be the SD380's most important features for this research program. This unit is transportable via a common wheeled laboratory cart, and is powered by 115 volts AC. The SD380 is presented in Figure 4.

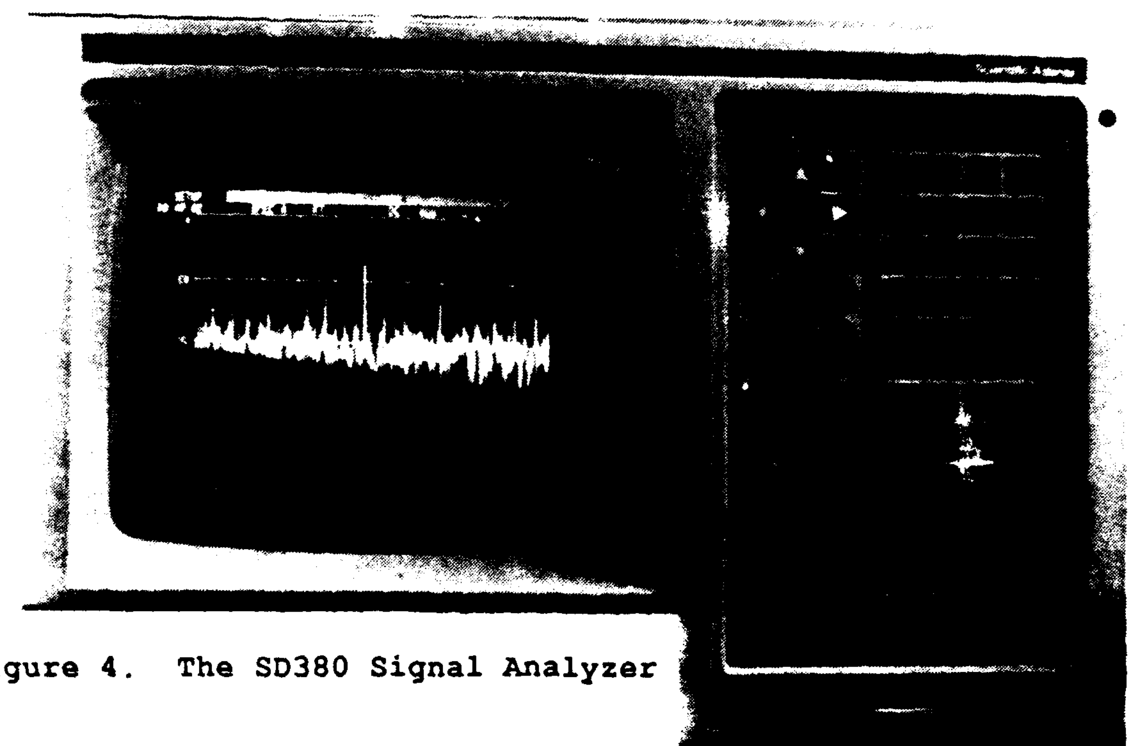


Figure 4. The SD380 Signal Analyzer

B. THE PCB CORP. SERIES 302B03 ACCELEROMETER

Measurement of the vibration levels during RPH operation was provided by PCB Corp. Series 302B03 piezoelectric accelerometers. These accelerometers are approximately 1.30 inches in length and .48 inches in diameter. This accelerometer maybe attached to the test object by means of an beryllium-copper stud or mounting wax. This particular model has a weight of approximately 25 grams and operates on +24 to 27 volts DC. The highly sensitive response of this accelerometer (300 millivolts/G) made it ideal for RPH testing. This accelerometer is presented Figure 5.

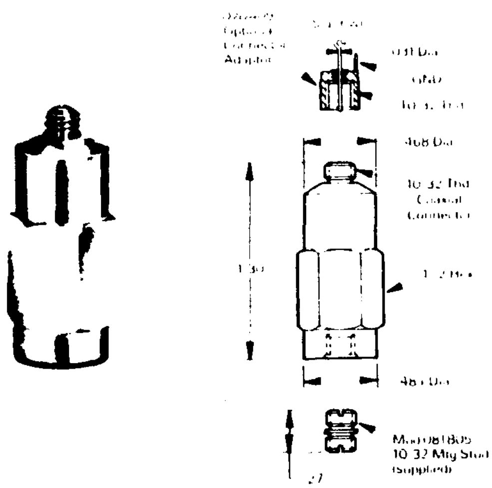


Figure 5. The PCB Corp. Series 302B03 Accelerometer

C. THE PCB CORP. MODEL 480B BATTERY POWER UNIT

The Series 302B03 accelerometer is powered using the PCB Corp. Model 480B Battery Power Unit. This power unit is designed to power low-impedance piezoelectric transducers such as the Series 302B03. This unit also contains built-in coupling circuitry to allow for direct connection to oscilloscopes, recorders, and signal analyzers. Power for the Model 480B power unit is provided by three 9 volt batteries mounted internal to the power unit chassis. The power unit is connected to the accelerometers using a miniature 25 ft. coaxial cable. Connection from the Model 480B power unit to the display device is by a similar coaxial cable, which terminates using a standard BNC connector at the spectrum analyzer input. This power supply is presented Figure 6. Additional details of the Series 302B03 accelerometer and Model 480B power unit are provided Appendix A.

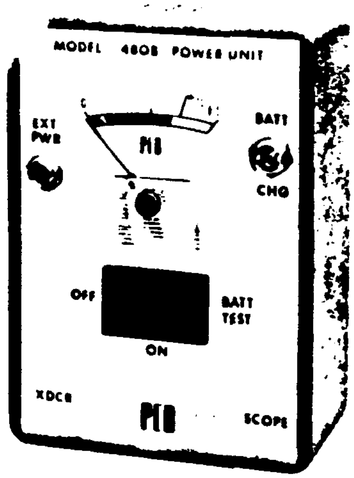


Figure 6. The PCB Corp. Model 480B Battery Power Unit

D. THE RPH DATA ACQUISITION SYSTEM

Design of the RPH data acquisition system was based on the requirement for the system to operate both while the RPH was on the ground and in a hover. This requirement was met by use of the 25 ft. coaxial cables described in Section C. These cables were long enough to allow the RPH to operate on the ground and hover out of ground effect (HOGE). This capability allowed for flight in the parking lot behind the NPS UAV Laboratory. Operation of the RPH behind the UAV Laboratory eliminated the need for portable power generators for the signal analyzer, and had the additional advantage of reducing the effects of wind upon test results.

The data acquisition system was designed to operate as follows: RPH mounted Series 302B03 accelerometers detected vibrations transferred to the airframe from the engine, main rotor, and tail rotor. These vibrations were converted to electrical signals within the accelerometer, which is powered by the Model 480B power unit. These electrical signals were transmitted via the coaxial cable to the Model 480B power unit. The power unit contains a coupling capacitor which allows for transfer of the accelerometer signal through the power unit to the spectrum analyzer using another coaxial cable without amplification or attenuation of the accelerometer signal. Display of the accelerometer signal is provided by the SD380 spectrum analyzer. This display was then recorded on the 3.5 in. floppy disk installed in the

SD380's internal disk drive. Data displays stored on the disk drive could then be plotted using a Hewlett-Packard Model 7475A Plotter via the IEEE 488 data bus. This data acquisition system is depicted in Figure 7.

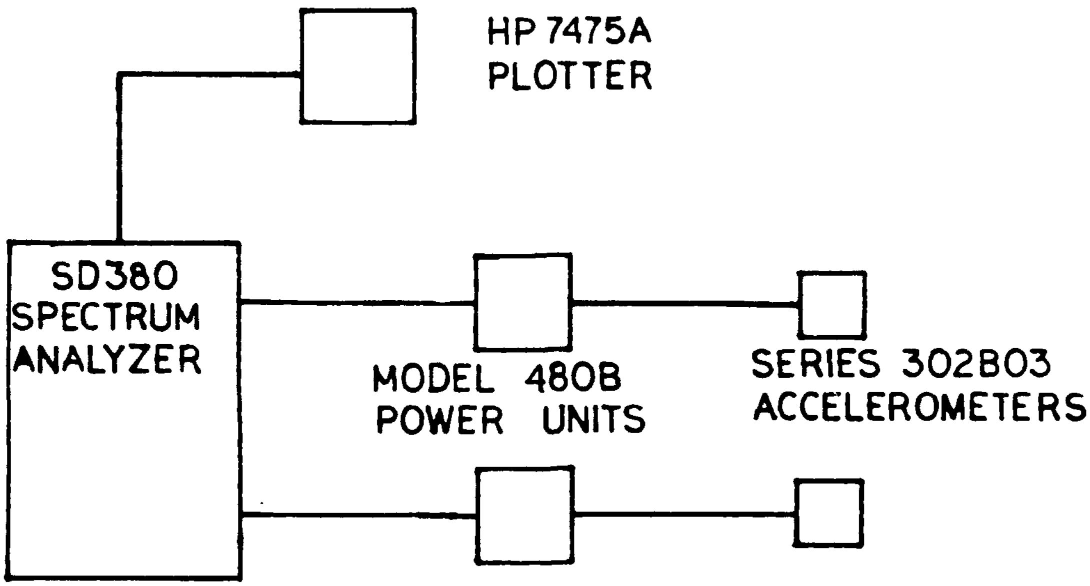


Figure 7. The RPH Data Acquisition System

V. METHOD OF TESTS

Development of a test program to measure and record the vibration levels experienced by the RPH test vehicles was arranged so that a gradual build-up of test complexity and pilot experience would yield sufficient data without undue risk to equipment. For this reason, a test schedule was developed using both the GMP **Legend** and the Pacific RPV Co. **Bruiser**. GMP **Legend** operations would allow for refinement and proof-of-concept testing for the RPH data acquisition system while also allowing the RPH pilot to gain experience with **Legend** handling qualities. Following proof-of-concept testing/pilot training with the **Legend**, ground and flight tests of the Bruiser would be performed. As noted in previous thesis efforts [References 14 and 15] the lack of an experienced RPH pilot was the single greatest obstacle to successful RPH flight testing of HHC. Use of the **Legend** for proficiency flying was and will continue to be an asset to the HHC program at NPS.

A. GMP LEGEND TESTS

Build-up efforts using the **Legend** were initiated in order to answer the following questions: 1) Will the data collection system be safe to operate? 2) Does the system have adequate sensitivity for the level of vibrations that may be

encountered? 3) What are the optimum locations for the accelerometers? 4) Will the researcher be able to distinguish the various contributors to the vibration levels? 5) And finally, does the **Legend** exhibit vibration traits similar to those for a full scale helicopter? These questions were addressed in subsequent test operations.

In order to investigate the **Legend** vibration profile, the accelerometers were mounted at either a fuselage location or on the tail boom, forward of the tail rotor assembly. During all test events, the **Legend** was established in a hover out of ground effect. As with a full scale aircraft, HOGE is a distance of at least one rotor diameter between the bottom of the fuselage and the ground. For the **Legend**, this distance was approximately 58 inches.

In order to ensure data accuracy, the accelerometers utilized for these tests were calibrated by the manufacturer prior to the beginning of tests. Calibration results may be found in Appendix B.

1. GMP Legend Fuselage Vibration Measurements

Measurements of vibration levels at the **Legend** fuselage were obtained by mounting two 302B03 accelerometers on a tri-axial block and attaching the tri-axial block to the underside of the aft skid support, along the centerline of the aircraft, approximately two inches aft of the gross weight center-of-gravity (CG). The tri-axial block was secured to

the skid with a #10-32 screw. The accelerometers were mounted on the tri-axial block so that RPH vertical and lateral accelerations could be detected. Coaxial cables were attached to the accelerometers and secured to the skid using plastic tie-wraps. The coaxial cable was then routed to the Model 480B power unit, and then to the SD380 spectrum analyzer. The **Legend** was then established in a hover. Analyzer displays of vibration levels were observed in a logarithmic vertical scale (vibration amplitude) using a frequency scale (horizontal axis) of up to 1000 Hz. Rotor RPM was measured using a Skytach Corp. strobe tachometer. Establishment of rotor RPM allowed for the rapid calculation of the 1/rev. frequency (main rotor). This frequency was determined by the following equation:

Main Rotor 1/Rev=(Main Rotor RPM/60 Hz.)

Once the main rotor 1/rev. frequency is determined, tail rotor, engine, and associated harmonics can be noted for the given main rotor operating RPM. Figure 8 depicts the **Legend** with accelerometers mounted for fuselage measurements. Flight testing of the **Legend's** fuselage vibration level is depicted in Figure 9.

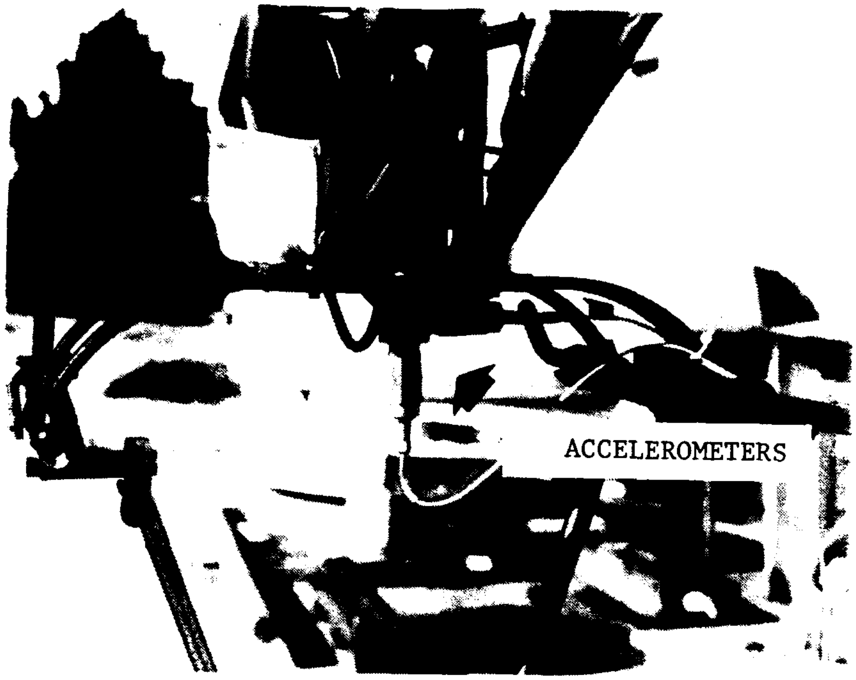


Figure 8. GMP Legend With Fuselage Accelerometer Mount

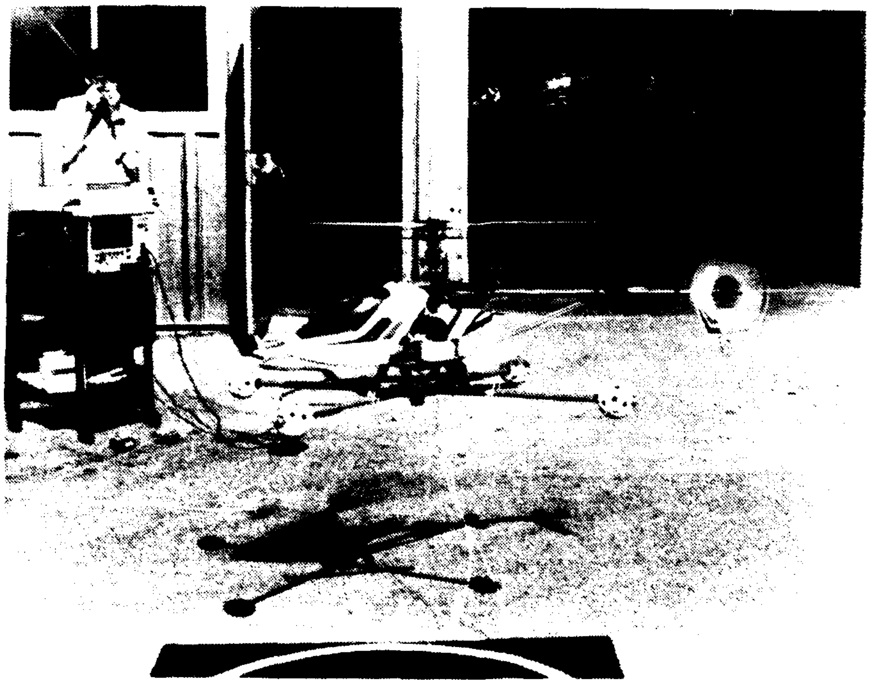


Figure 9. GMP Legend Fuselage Vibration Measurements Testing

2. GMP Legend Tail Boom Measurements

Vibration levels on the tail boom were measured using accelerometers mounted on the tri-axial block in a manner similar to that utilized for fuselage measurements. For this test, the block was secured to the tail boom 27 inches aft of the main rotor shaft, and 24.5 inches aft of the gross weight CG. An aluminum strap and block assembly secured the tri-axial block to the tail boom, and tie-wraps were used to fasten the coaxial cables to the tail boom and skid assemblies. The **Legend** was established in a hover identical to the method used for fuselage measurements, and vibration levels were observed and recorded with the SD380 spectrum analyzer. Figure 0 depicts the **Legend** with the accelerometers mounted n the tail boom. Flight testing of tail boom vibration levels is depicted Figure 11.

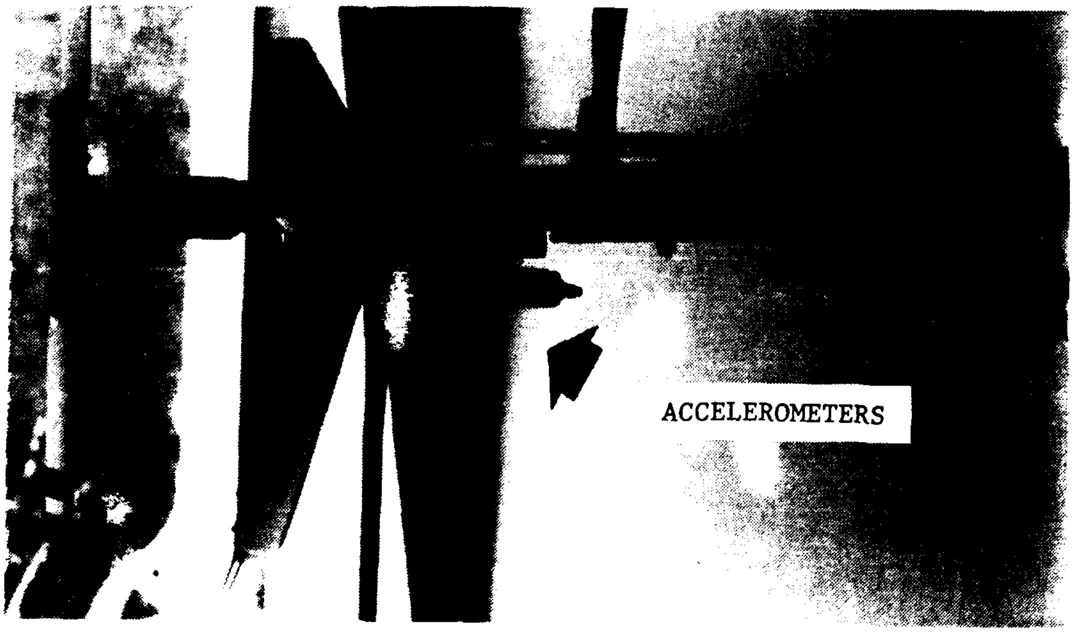


Figure 10. GMP Legend With Accelerometers Mounted On Tail Boom

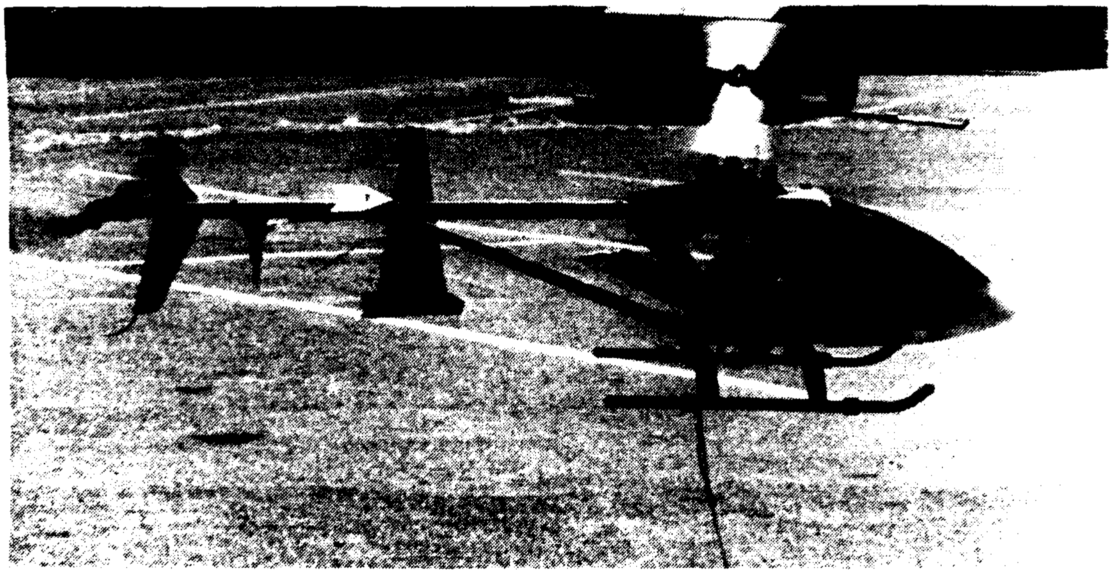


Figure 11. GMP Legend Tail Boom Vibration Measurements Testing

3. GMP Legend Main Rotor Imbalance Measurements

Measurements of the effects of a main rotor system unbalance were performed to: 1) Make a qualitative analysis of the data acquisition system sensitivity; and 2) Examine the change in vibration levels experienced by the **Legend** with a main rotor unbalance, in particular at the main rotor 1/rev frequency. A rotor system unbalance was created by sliding one of the two main rotor flybar balance masses in toward the main rotor mast a distance 1.75 inches inboard from the normal balance mass position. This mass, which weighs approximately .5 ounces, was secured in the test position on the flybar by means of a setscrew. For this test, the tri-axial block with accelerometers was mounted on the tail boom

in a manner identical that used for tail boom vibration tests. The aircraft was then established in a hover. Vibration levels were monitored and recorded using the SD380 spectrum analyzer. This test was repeated with the balance mass at a position 3.5 inches inboard from the normal balance mass position. Figures 12 and 13 show the **Legend** main rotor system flybar balance weight at the 1.75 and 3.5 inch test positions.

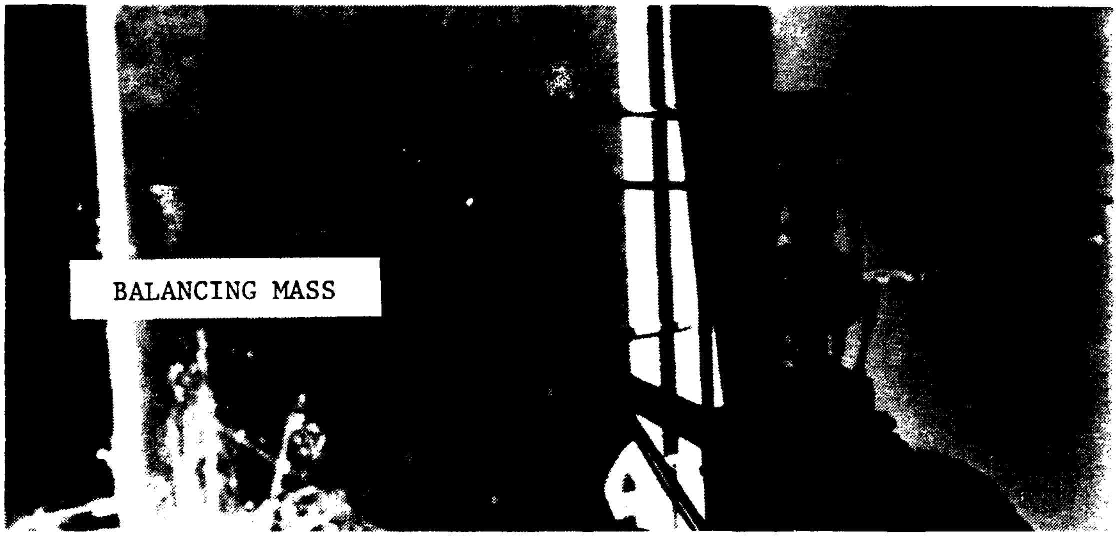


Figure 12. GMP Legend With Balance Weight 1.75 Inches Inboard

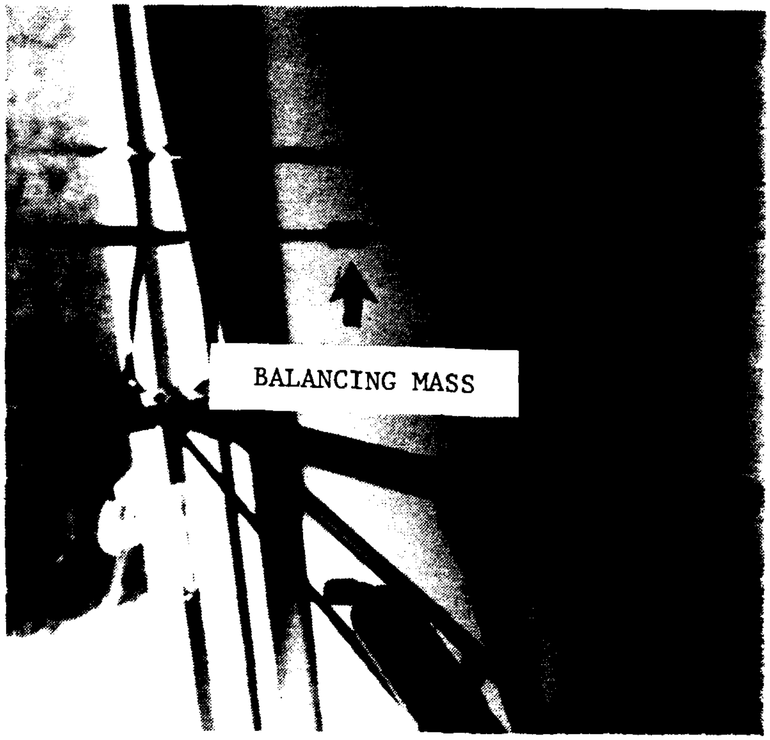


Figure 13. GMP Legend With Balance Weight 3.5 Inches Inboard

B. PACIFIC RPV CO. BRUISER TESTS

1. Ground Tests

Test instrumentation and data collection methods utilized for the **Legend** flight testing were readily adapted for use on the **Bruiser**. An adaptor block machined from aluminum bar stock allowed for the attachment of the tri-axial block directly to the **Bruiser's** fuselage aft skid mount. As with the **Legend**, two Series 302B03 accelerometers were mounted on the tri-axial block for detection of vertical and lateral accelerations. Coaxial cable routing and spectrum analyzer initialization was identical to the methods used

during **Legend** flight testing. Figure 14 depicts the **Bruiser** with accelerometers mounted for fuselage measurements.

Ground tests were conducted by operating the engine and rotor systems while the **Bruiser** remained on its skid structure. Main rotor RPM was measured using the Skytach tachometer. Vibration levels, characteristic frequencies, and harmonics of rotating components were observed using the SD380 spectrum analyzer. Storage of these results using the SD-380's 3.5 inch disk drive assisted in data reduction and analysis efforts.

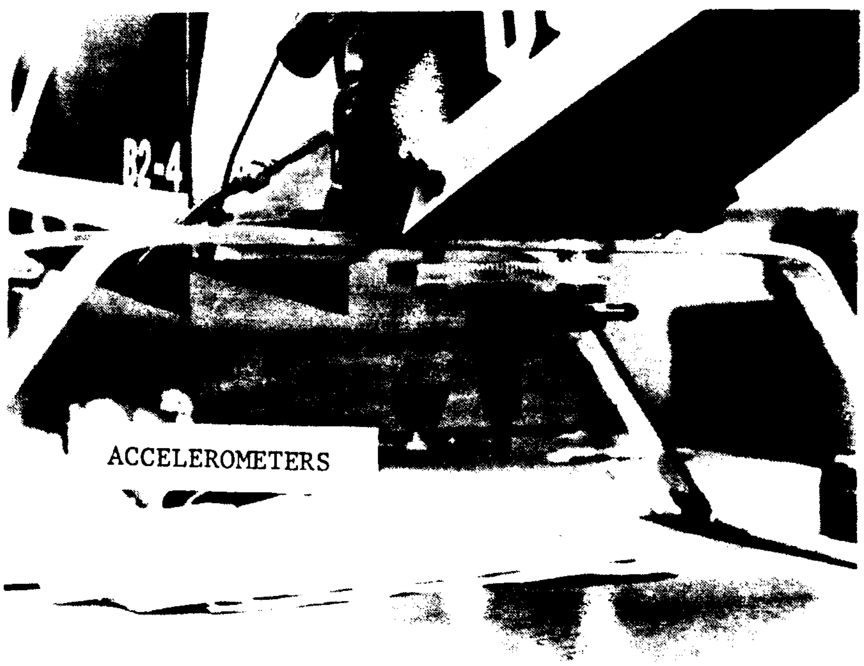


Figure 14. Pacific RPV Co. Bruiser With Fuselage Accelerometer Mount

This test program was developed with the intent of measuring the **Bruiser's** ground and "in-flight" vibration levels. However, failure of the engine/main rotor drive assembly clutching mechanism at the conclusion of ground tests prevented flight measurements from being accomplished in time to meet the established schedule.

VI. RESULTS AND DISCUSSION

A. GENERAL

All data collected during **Legend** and **Bruiser** testing was stored in individual data files using the SD380 3.5 in. floppy disk drive. Reduction and analysis of this data was accomplished by recalling the respective data file to the SD380 spectrum analyzer cathode ray tube (CRT) display. The SD380 cursor function was then used to identify both frequency and amplitude of the displayed acceleration peaks. The scaling of the vertical axis (amplitude) was calibrated in a logarithmic scale. This was the scale selected for the data analysis reported in this thesis. If desired, a linear scale could also be selected for the vertical axis when using the SD380 spectrum analyzer. For these tests, the basic unit of measurement established on the logarithmic vertical scale was the user-created **Engineering Unit (EU)** sub-function. This EU sub-function was initialized so that:

1 Engineering Unit = 1 "G"

The horizontal axis was displayed in units of frequency on a linear scale. Measurement of the main rotor RPM for the **Legend** and **Bruiser** permitted rapid calculation of the various characteristic frequencies and their respective multiples for the respective RPH. The CRT data display was transferred to

hard copy (paper) plots using the HP 7475A plotter. These plots are presented in Appendices C, D, E, and F.

B. GMP LEGEND MEASUREMENTS

1. Fuselage Measurements

Combined vertical and lateral vibration results are presented in Appendix C, Figure 1. From these plots, it was noted that engine 1/rev. (1P) was the dominant vibration component in both the lateral and vertical axes. Main rotor 1/rev. or 1P[1] was difficult to identify using the combined lateral/vertical scale. It was observed during these tests that the main rotor, tail rotor, and their associated harmonics were difficult to identify if the RPH was still in ground effect (IGE) (when the data was stored to the 3.5 in. disk). This may explain the lack of useful data from the combined lateral/vertical plot. Figure 2 is an expanded view of the lateral vibration measurements. Engine 1P is most evident at a value of .305 EU's (.305 G). Main and tail rotor frequency amplitudes remain at or below the noise floor, and cannot be identified. Engine 1P, 2P, and main rotor 1P, 2P, and 4P frequencies are clearly identified as vertical accelerations in Figure 3. Maximum amplitude of main rotor 1P was .07 G. Main rotor 2P appears to be a slightly greater

[1] A standard convention that has been adopted for convenience in helicopter dynamics is to abbreviate the statements 1/rev., 2/rev.,...etc. by 1P, 2P,...etc. This notation has been adopted in this thesis.

value than main rotor 1P, as would be expected. Noteworthy in these fuselage measurements is the fact that the engine 1P is of a greater value in the lateral axis (.305 G) than in the vertical axis (approx. .10 G). In addition, main rotor 1P and associated harmonics were observed when measured in the vertical axis, but did not appear in lateral measurements. Tail rotor 1P could not be identified in either the lateral or vertical axes using the fuselage accelerometer mount. Finally, engine 1P is the frequency of greatest amplitude as compared with all other characteristic frequencies. This is not typical of a full scale helicopter, where for a 2-bladed design the main rotor 2P would be the dominant frequency, with engine and drive train components of lesser magnitude.

2. Tail Boom Measurements

Vibration measurements at the **Legend** tail boom accelerometer location are presented in Appendix D. Figure 1 of Appendix D is a combined lateral/vertical plot which again shows the predominance of the engine 1P frequency in both axes. Main rotor 1P and 2P frequencies (27.5 and 55 Hz, respectively) are clearly defined when measured in the lateral axis, but are not visible in the vertical axis. This is in contrast to fuselage measurements, in which the main rotor 1P and 2P characteristic frequencies were of greatest amplitude when measured in the vertical axis. Main rotor 4P appears in the vertical axis.

An expanded view of the lateral axis is presented in Figure 2. From this plot, main rotor, tail rotor, and engine frequencies with their associated harmonics appear sharply defined. This recording position (lateral, tail boom) provided the best overall view of the helicopters' characteristic frequencies as compared with the fuselage measurement position. Of particular interest is the strength of the main rotor 1P vibration. Normally, for a two-bladed helicopter the 2P would be of greatest amplitude. However, the **Legend** 1P was the frequency of greatest amplitude, next to that of engine 1P. In a full scale helicopter strong 1P indications generally typify a mass imbalance in the main rotor system or the result of a blade being "out of track". During test flights of the **Legend** no unusual fuselage motion or blade track anomalies were observed. Therefore, the reason for the **Legend's** strong main rotor 1P response is unknown. One possible cause of this relatively high 1P reading could be the presence of an airframe natural frequency or mode which is near 1P. Particularly suspect in this case would be the presence of a lateral bending mode. The best means for resolving this question would be to conduct a vibration survey of the fuselage (airframe). Such tests are planned in the future. As a final note, increasing the speed of the main rotor system from 1502 (Figure 2) to 1650 RPM (Figure 1) resulted in a decrease in the level of vibrations as measured at the tail boom. Such a change in response with change in

frequency supports the theory that the high 1P response is at least partially due to the proximity of a fuselage mode to 1P.

3. Main Rotor Mass Imbalance Measurements

The effects of a mass imbalance in the main rotor system were studied by measuring the vibration level at the tail boom in both the lateral and vertical axes. As noted in para. 2, this tail boom location was chosen because it provided the best response to the **Legend's** characteristic frequencies (main rotor, tail rotor, etc.). Results from this phase of testing are presented in Appendix E.

Appendix E, Figure 1 shows lateral vibration measurement results with the main rotor flybar balance mass 1.75 in. inboard from the normal trim position. This is equivalent to introducing into the system an unbalance delta of 0.5 in.-lbs. The characteristic frequencies plotted in Figure 1 show that a mass imbalance in the main rotor system of this magnitude results in an increased main rotor induced 1P amplitude in the airframe. As compared with Appendix D, Figure 2, a change of .04 EU (.04 G) in the airframe lateral response resulted from main rotor 1P excitation with introduction of .05 in.-lbs. of unbalance. Main rotor 2P appears unchanged as expected. Also, engine 1P showed it is unchanged, as expected.

Figure 2 of Appendix E is a combined lateral/vertical plot of tail boom vibration levels with the balancing mass located 3.5 in. inboard from the normal balancing mass trim position.

This is equivalent to doubling the unbalance delta from .05 in.-lbs. to .10 in.-lbs. As expected, tail boom lateral measurements show higher levels of vibration than those measured in the vertical axis, though main rotor 1P and 2P are clearly identifiable in both axes. Main rotor 1P shows significant increase in amplitude over normal levels. Main rotor 10P showed the greatest increase in amplitude. Small changes in main rotor operating speed did not appear to change vibration levels as recorded during these tests, indicating that if there was proximity with any airframe modes, we were not dwelling precisely on a mode. Tail rotor 1P shows a significant increase in amplitude as compared with normal balanced main rotor operation. This is due to the induced motion of the tail rotor hub. An expanded view of lateral axis measurements is presented in Figure 3. With the balance mass 3.5 in. inboard (for an unbalance of .10 in.-lbs.), tail rotor 1P has increased to an amplitude of approximately .43 EU (.43 G). This is an increase of approximately .30 EU (.3 G) when compared with normal main rotor operation (Appendix D, Figure 2). A summary of the results of the tests with rotor unbalance is given in Table V.

TABLE V. MAIN ROTOR MASS UNBALANCE TEST RESULTS

Mass Unbalance Location (inboard)	0	1.75 in.	3.5 in.	3.5 in.
Main rotor RPM	1502	1687	1650	1687
1P Lat. Vibrations	.134 G	.175 G	.333 G	.432 G
1P Vert. Vibrations	-----	-----	.217 G	-----

NOTE: "-----" denotes measurement not recorded.

C. PACIFIC RPV CO. BRUISER GROUND TEST MEASUREMENTS

As stated in **Method of Tests,** baseline vibration measurements of the Pacific RPV Co. **Bruiser** were limited to ground tests with the accelerometers mounted at the aft skid support (centerline) position on the fuselage. Appendix F contains the results of the **Bruiser** ground tests. Appendix F, Figures 1 through 3 contain the results of the lateral/vertical vibration measurements. Figure 1 shows a distinct main rotor 4P in both the lateral and vertical axes. At a 4P frequency of 77.5 Hz., the amplitude recorded at the fuselage was .335 G in the lateral and .674 G in the vertical axis. Tail Rotor 1P is slightly more sharply defined in the lateral axis as compared with the vertical (Figure 2). Engine 1P may be identified in both axes (Figure 3), though it is of greater amplitude in the vertical.

Figures 4 through 8 are views of the vertical axis accelerations up to a maximum frequency of 400 Hz. Figure 4 annotates the main rotor 1P, at an amplitude of .103 G. Note

that this amplitude for 1P is only 23% of main rotor 2P (Figure 5) and 13% of main rotor 4P (Figure 6). Main rotor 4P was the characteristic frequency of greatest amplitude recorded during ground tests of the **Bruiser**. This result compares favorably to full scale 4-bladed helicopter vibrations, where the n/rev. operating frequency is typically of highest value. Tail rotor 1P (Figure 7) and Engine 1P (Figure 8) were quickly identified through the gearing ratios (6 * MR 1/rev., and 8 * MR 1/rev., respectively), with amplitudes within .10 G of each other.

As with the **GMP Legend**, the vertical axis accelerometer indicated the highest level of vibration for the fuselage accelerometer mount. Attempts to measure vibration levels of the **Legend** on the ground resulted in only the engine 1P being identified. This was not the case with the **Bruiser**, as all frequencies of interest were identified without the RPH becoming "light on the skids". The ability to obtain a characteristic frequency spectrum of the **Bruiser** while still on the ground is indicative of the higher level of vibrations (as compared with the **Legend**) transferred from the main rotor system during movement (i.e. rotation) of its dynamic components to the fuselage.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. General

a. The data acquisition system was safe to operate during all ground and flight tests.

2. The GMP Legend

a. The data acquisition system was of adequate sensitivity and bandwidth to detect and display the characteristic frequencies of the two-bladed **Legend's** dynamic components.

b. The tail boom, lateral axis, was determined to be the optimum location for detection of all characteristic frequencies of the **Legend's** dynamic components.

c. Using the tail boom-mounted, lateral axis accelerometer the author was able to identify main rotor, tail rotor, and engine frequencies and their harmonics as displayed on the SD380 spectrum analyzer.

d. The **Legend** exhibited a vibration profile similar to that of a full scale helicopter with the following exception: the **Legend's** engine 1P and main rotor 1P vibrations showed amplitudes that were too high when compared with normal two-bladed helicopter dynamic response. The high main rotor

1P response is probably due to the proximity of an airframe lateral mode to 1P, as evidenced by the sensitivity of the 1P response to changes in RPM. For the high engine 1P, no comparison can be made, since the equivalent full-scale helicopter has a turboshaft engine instead of a reciprocating engine.

e. The **Legend** was ideally suited as a remotely piloted helicopter for both pilot training and instrumentation development. Instrumentation methods developed using the **Legend** were effectively applied to subsequent **Bruiser** ground tests.

3. The Pacific RPV Co. Bruiser

a. The data acquisition system was of adequate sensitivity and bandwidth to detect and display characteristic frequencies of the four-bladed **Bruiser's** dynamic components.

b. The fuselage accelerometer location, vertical axis, was satisfactory for the detection of vibrations experienced within the **Bruiser's** airframe.

c. Main rotor, tail rotor, and engine frequencies, including harmonics, could be distinguished easily from data collected during ground tests of the **Bruiser**.

d. The **Bruiser** exhibited vibration traits similar to a full scale four-bladed helicopter. Main rotor 4P was the frequency of greatest vibration amplitude, with engine and tail rotor of lesser value.

e. Similarity of the **Bruiser's** vibration profile to that of a full scale helicopter will assist the researcher in correlating future **Bruiser** HHC operation test results to that of full scale four-bladed operation.

B. RECOMMENDATIONS

1. General

a. Continue use of the **Legend** for light weight instrumentation development and pilot proficiency.

b. Modify the **Bruiser** with a HHC system that will operate in an open loop mode.

c. Conduct tests with the HHC-modified **Bruiser** to examine the effect of HHC has on helicopter vibration and performance in hover and forward flight.

2. Specific

a. Conduct further tests of the **Bruiser** using tail boom locations for accelerometer mounting.

b. Conduct hover flight tests of the **Bruiser** to compare in-flight vibration levels with those experienced during ground test operations.

c. Develop an instrumentation system which will telemeter vibration data to a ground receiving station without a "hard wire" connection.

d. Conduct laboratory vibration surveys for both the **Legend** and **Bruiser** to identify both mode shapes and frequencies of the primary airframe modes.

e. As part of the vibration surveys recommended in para. d., conduct a detailed survey of the response of the **Legend** airframe to excitation from 1450 RPM to 1700 RPM in an effort to explain the high 1P response levels measured during the model flight test program reported in this thesis.

APPENDIX A

LOW IMPEDANCE, VOLTAGE MODE

QUARTZ ACCELEROMETER

with built in amplifier

Series 302A

- built-in unity-gain amplifier; enhances resolution
- high level (5V), low impedance (100 ohm) analog output
- drives long coaxial or 2-wire cables
- inverted, isolated compression structure
- standardized sensitivity; suppressed resonance
- simplified systems; low per channel cost
- insensitive to cable length or motion

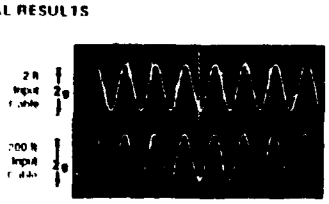
Use Model 302A for routine measurement of vibration and shock in laboratory, field, flight, vehicular and industrial applications.

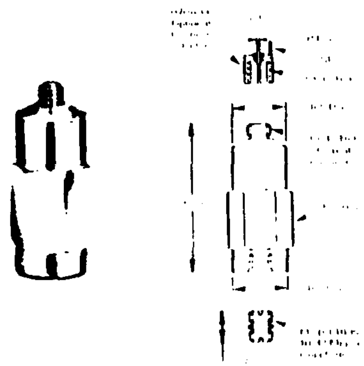
Model 302A, a precision quartz accelerometer, measures the acceleration aspect of shock and vibration motion from 1g to 500g, over a wide frequency range and under adverse environmental conditions. Sensitivity is standardized at 10 mV g. Like most quartz transducers, this instrument offers exceptionally good low frequency response and follows long duration shock events up to 20 millisecond duration. An optional shock Model 302A02 measures transient events to 0.5 second duration.

Quartz accelerometers are installed by clamping the precision base surfaces in intimate contact with the adjacent structure of the test object, usually by means of an elastic beryllium copper stud. Adhesive and magnetic mounting bases facilitate quick installation for structure testing. Since the force moving the instrument is transmitted through this interface, it is important that the mating surface be machined flat. For severe shock environments the optional solder pin connector adaptor has proved more reliable than coaxial components.

For convenience in ordering and portability these instruments are offered in assembled kit form, as illustrated, complete and ready to install by connecting to your readout instrument and operate. Standard options include ground isolation, longer time constant, higher sensitivity and welded hermetic seal. A variety of battery or line power signal conditioners (with or without gain) in single or multi channel configurations meet most all applications.

TYPICAL RESULTS

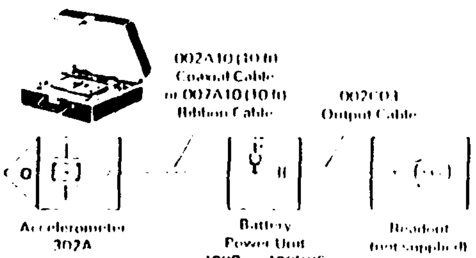




SPECIFICATIONS: Model No.		302A
Range, FS (+5 volt output)	g	±500
Resolution	g	0.01
Useful Overrange	g	1000
Sensitivity (±2%)	mV/g	10
Resonant Frequency (mounted)	Hz	30 000
Discharge Time Constant (at 70°F)	s	≥0.5
Frequency Range (±5%)	Hz	1 to 5000
Frequency Range (±10%)	Hz	0.7 to 10 000
Amplitude Linearity	%	1
Overload Recovery	μs	10
Output Impedance	ohm	<100
Strain Sensitivity	g/μin/in	0.01
Transverse Sensitivity	%	≤5
Temperature Coefficient	%/°F	0.03
Temperature Range	°F	-100 to +250
Vibration/Shock (max)	g	2000/5000
Weight	gm	25
Excitation (constant current)	mA	2 to 20
Voltage to Current Regulator	VDC	+24 to 27
Optional Models.		**Model No**
Shock (TC 10 second)		302A02
High Sens (300 mV/g larger size)		302B03
Gen Purpose, Gnd ISO, 10 mV/g		302A04
High Freq 10kHz (version of 302A)		302A05
High Freq 10kHz (version of 302A04)		302A06
Triaxial 1 inch Cube		306A

Use prefix "H" to specify hermetic sealing e.g. H302A

Typical Systems: K302A battery power kit is shown below. Also available as GK302A with gain. Recharge and long life external battery pack options available.



A.C. MODE, BASIC

BATTERY POWER UNIT

for voltage mode transducers

Model 480B

- powers transducers with built in or attached amplifiers
- supplies constant-current power over the signal lead
- monitors normal or faulty system operation
- internal or external charge options

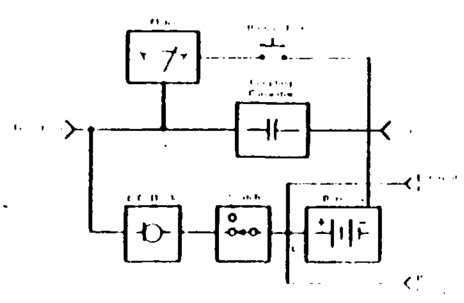
For powering low impedance piezoelectric transducers with built in or attached amplifiers and coupling them to oscilloscopes, meters or recorders, especially in field, low noise or test and evaluation applications.

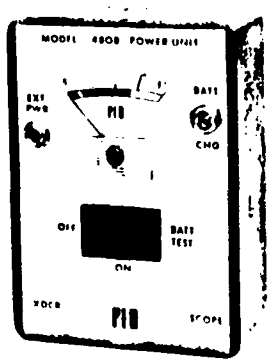
New model 480B features +27 volt power, provided by three standard 9 volt batteries connected in series, to extend the dynamic range of many ICP transducers to 10 volts output. Other features include an external DC power jack for use with *optional rechargeable* battery pack Model 073B05 and a battery charge jack for use with Model 488B Battery Charger NiCd Battery option.

A decoupling capacitor located behind the output connector removes DC bias on the output signal and provides a drift free A.C. mode of operation. The self test meter circuit, monitoring bias on the signal, indicates normal operation (green), short (red), or open circuit (yellow). It also checks battery voltage (+27V) when the rocker switch is depressed to the right. Circuits are housed in a shielded plastic case with a metal panel. Connectors are coaxial micro 10-32 jacks. Optional BNC connectors models are available.

Sensor kits including Model 480B Power Unit simplify specifying and ordering. These kits contain the sensor (transducer), sensor cable (10 ft. long), power unit, scope cable (3 ft long terminated in BNC) and accessories. To specify, add prefix K to the sensor model number and add prefix cost to the sensor price. Use prefix KR to specify kit with NiCd battery and charger option, e.g. KR302A Accelerometer Kit. When connected to a one or greater megohm input impedance, frequency response is essentially that of the transducer and the transducer signal is neither amplified nor attenuated. Constant current excitation improves the linearity and cable driving ability of the system.

BLOCK DIAGRAM



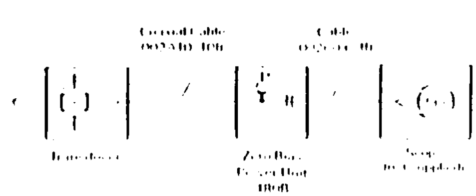


SPECIFICATIONS: Model No.		480B
Transducer Excitation	VDC	+27
Excitation Current	mA	2
Voltage Gain		1
Coupling Capacitor	μF	10
D.C. Offset (max into 1 megohm load)	mV	30
Battery (3 supplied)	V	9
Battery life	hr	160
Connectors (Input & Output)		10-32
Meter Monitor	VFS	27
Size (W.H.L)	in	2.9 x 4 x 1.5
Weight (incl batteries)	oz	15

Optional models:	Model No
With BNC input and output	480B02
With gain X1, X10, X100	480D06
Model 480D06 with BNC s	480D09
Integrating, velocity or acceleration	480A08
Optional accessories:	
Charger with three NiCd batteries	488B
Rechargeable external battery pack	073B05

To specify a complete power kit including power unit, 10 foot input and 3 foot output cable and storage case, add prefix K or KR (for rechargeable) to model number, e.g. K480B or KR480B.

TYPICAL SYSTEM



APPENDIX B

Calibration Certificate

Per ISA-RP37.2

Model No. 302303

Serial No. 19556

PO No. ______ **Customer** ______

Calibration traceable to NIST (NBS) thru Project No. 732/245191-90

ICP™ ACCELEROMETER
with built-in electronics

Calibration procedure is in compliance with MIL-STD-45662 and traceable to NIST. (NBS)

CALIBRATION DATA

Voltage Sensitivity	300.9	mV/g
Transverse Sensitivity	4.0	%
Resonant Frequency	21	kHz
Time Constant	0.2	s
Output Bias Level	11.1	V

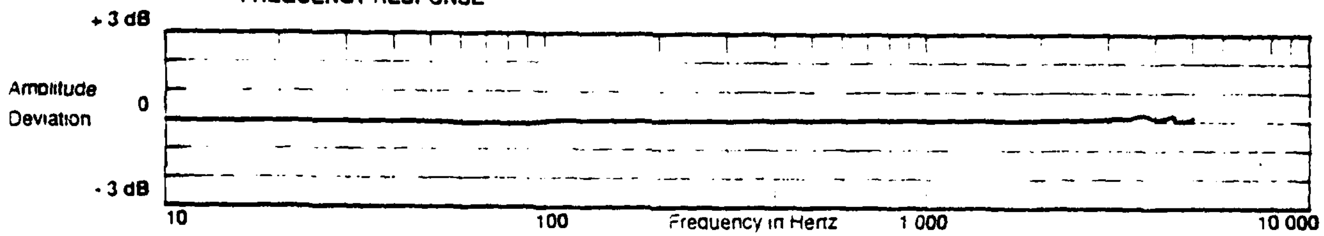
KEY SPECIFICATIONS

Range	16	±g
Resolution	0.0025	g
Temp. Range	-65/+175	°F

METRIC CONVERSIONS:
ms^{-2} = 0.102 g
°C = 5/9 x (°F -32)

					Reference Freq.					
Frequency Hz:	10	15	30	50	100	300	500	1000	3000	5000
Amplitude Deviation %:	-1.4	-.6	-.5	-.7	0.0	.1	.4	.5	1.7	1.8

FREQUENCY RESPONSE



PCB Piezotronics, Inc. 3425 Walden Avenue Depew, NY 14043-2495 USA
716-684-0001

Date 1/10/91

Calibrated by ______

Calibration Certificate

Per ISA-RP37.2

Model No. 302A03

Serial No. 19138

PO No. ______ **Customer** ______

Calibration traceable to NIST thru Project No. 732/245191-90

ICP® ACCELEROMETER

with built-in electronics

Calibration procedure is in compliance with MIL-STD-45662A and traceable to NIST.

CALIBRATION DATA

Voltage Sensitivity	299.3	mV/g
Transverse Sensitivity	5.0	%
Resonant Frequency	21.5	kHz
Time Constant	0.2	s
Output Bias Level	11.4	V

KEY SPECIFICATIONS

Range	16	±g
Resolution	0.0025	g
Temp. Range	-65/+175	°F

METRIC CONVERSIONS

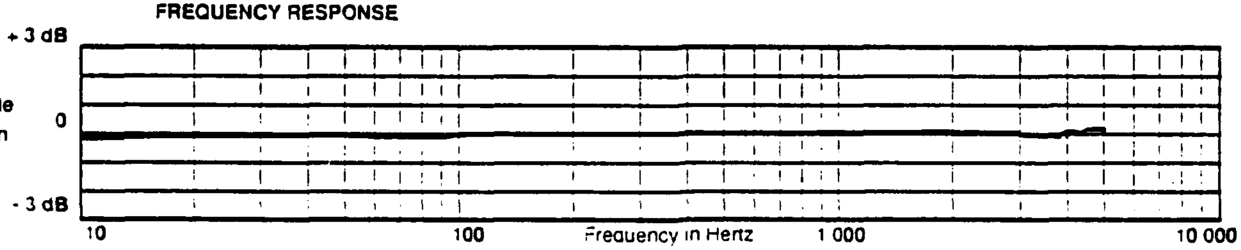
ms⁻² = 0.102 g

°C = 5/9 x (°F -32)

Reference Freq.

Frequency Hz	10	15	30	50	100	300	500	1000	3000	5000
Amplitude Deviation %	-2.2	-1.2	-.7	-.9	0.0	.2	.3	.5	-.7	1.5

FREQUENCY RESPONSE



PCB Piezotronics, Inc. 3425 Walden Avenue Depew, NY 14043-2495 USA

716-684-0001

Date 7/1/91

Calibrated by ______

APPENDIX C

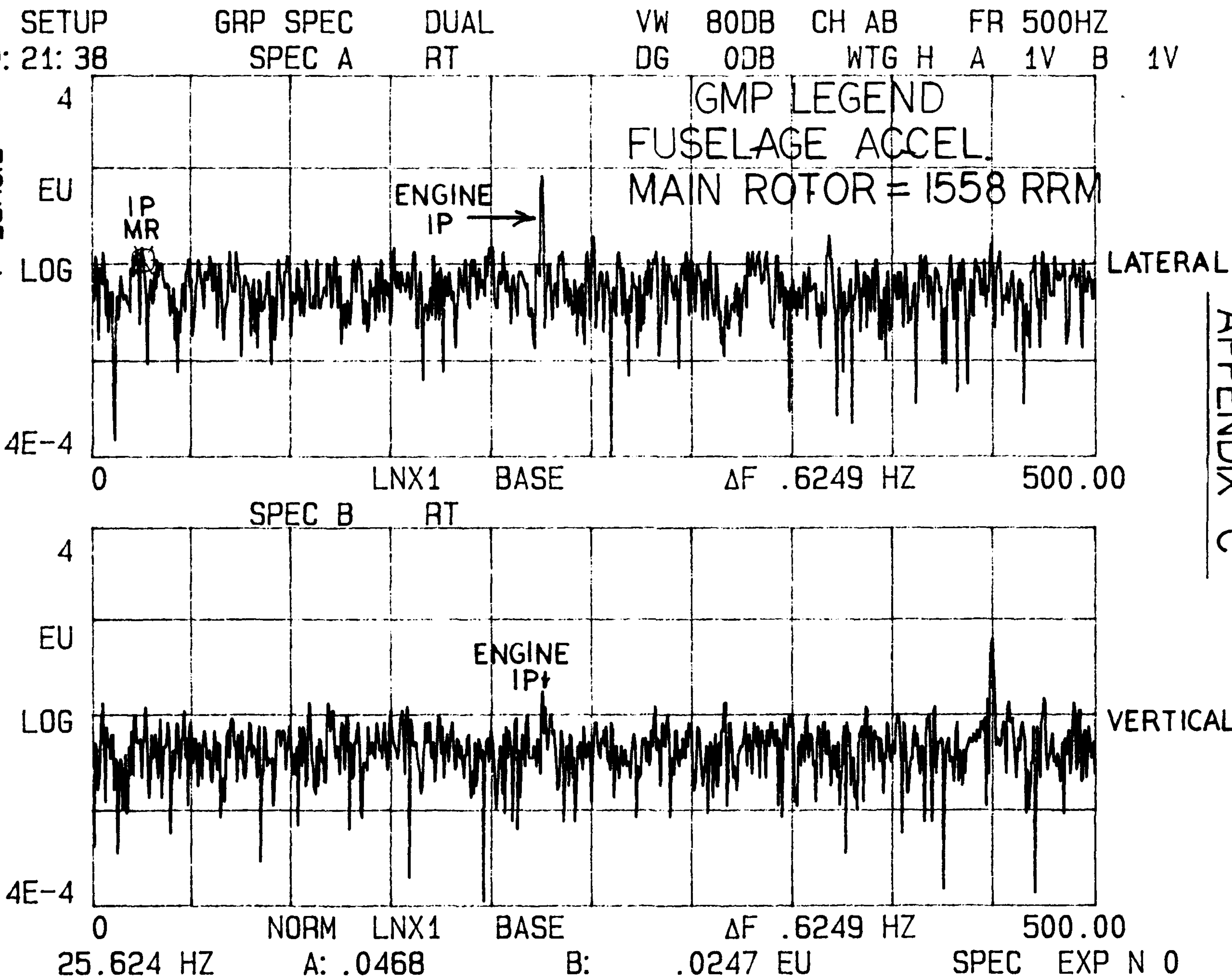
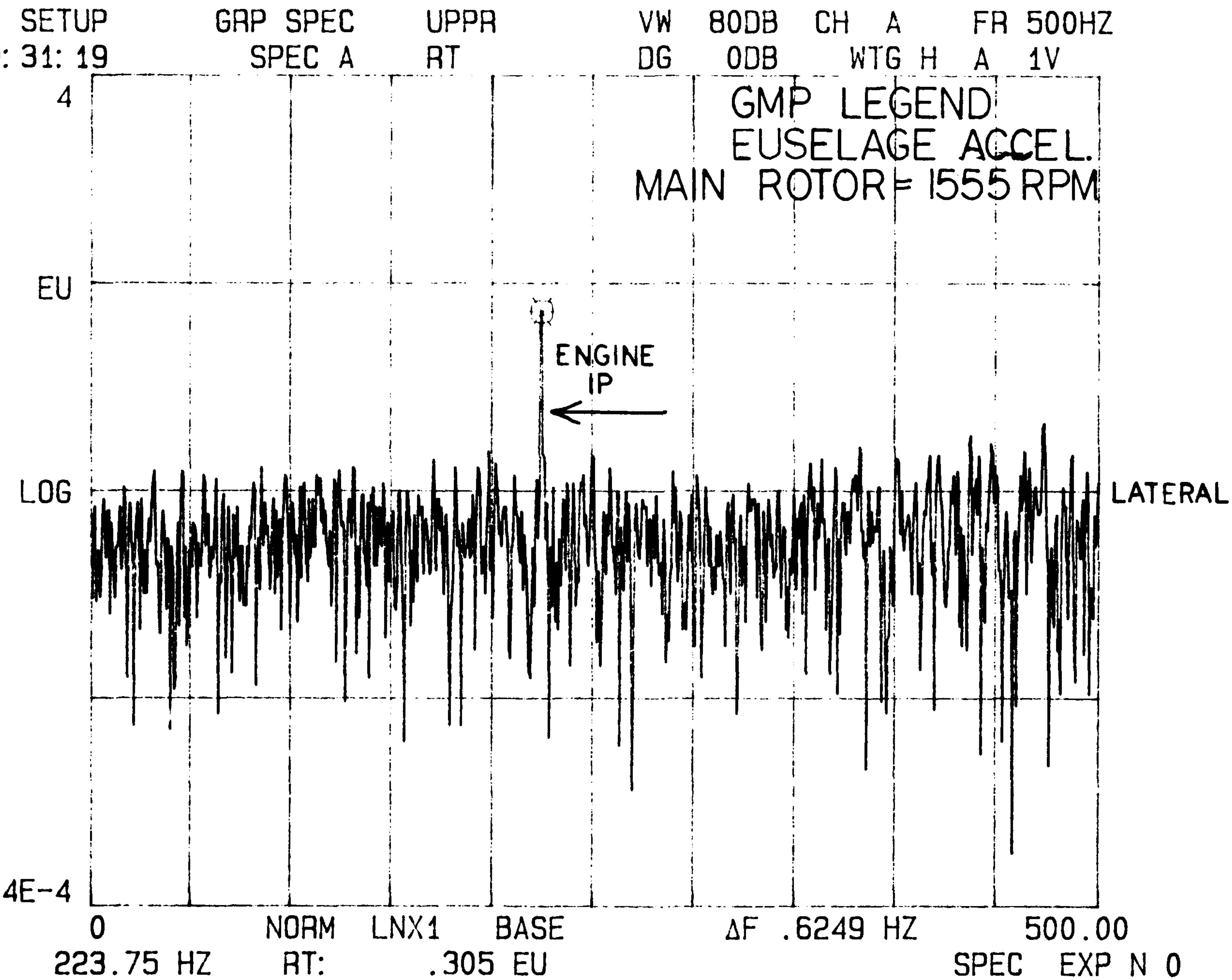


FIGURE 1.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SPEC A
UPPR
RT
VW
DG
80DB
0DB
CH A
WTG H
FR 500HZ
A 1V
GMP LEGEND
EUSELAGE ACCEL.
MAIN ROTOR = 1555 RPM
4
EU
LOG
4E-4
ENGINE
IP
LATERAL
0
223.75 HZ
NORM
RT:
LNX1
BASE
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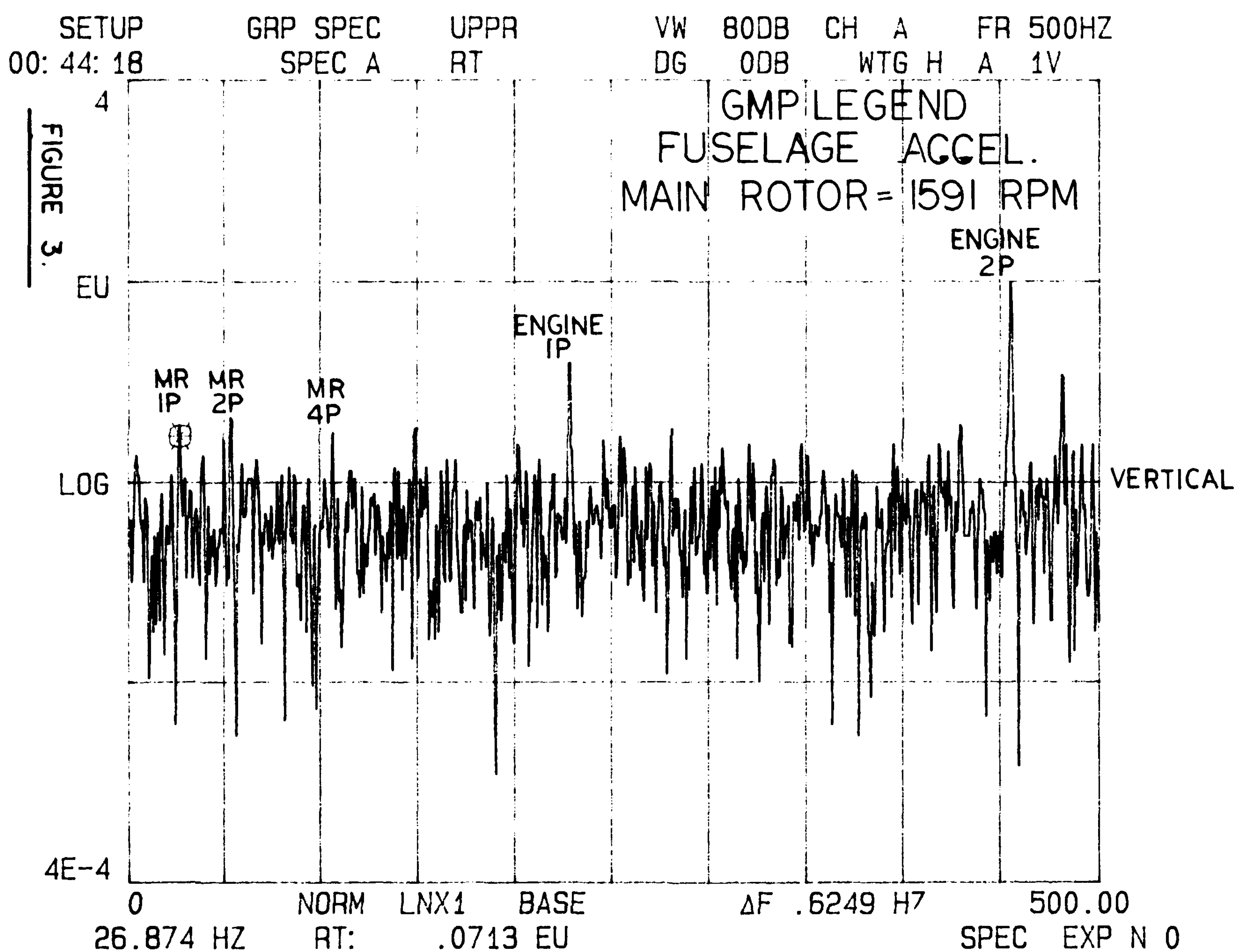
ΔF .6249 HZ
500.00
SPEC EXP N 0

FIGURE 2.


SETUP
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SPEC A
UPPR
RT
VW
DG
80DB
0DB
CH A
WTG H A
FR 500HZ
1V
GMP LEGEND
FUSELAGE ACCEL.
MAIN ROTOR = 1591 RPM
4
EU
LOG
4E-4
MR
1P
MR
2P
MR
4P
ENGINE
1P
ENGINE
2P
VERTICAL
0
NORM
LNX1
BASE
ΔF .6249 H7
500.00
26.874 HZ
RT:
.0713 EU
SPEC EXP N 0

FIGURE 3.

APPENDIX D

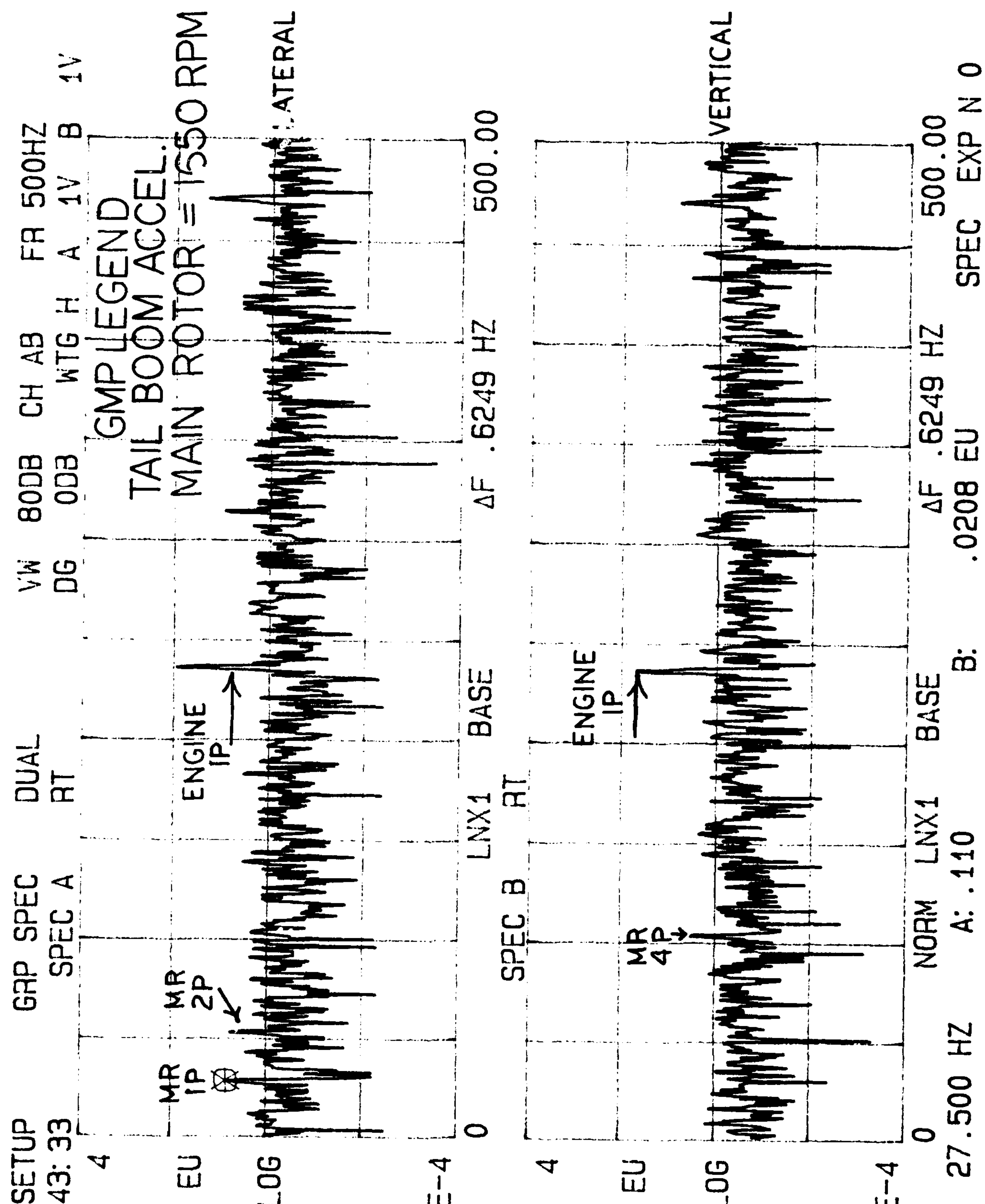

FIGURE I.

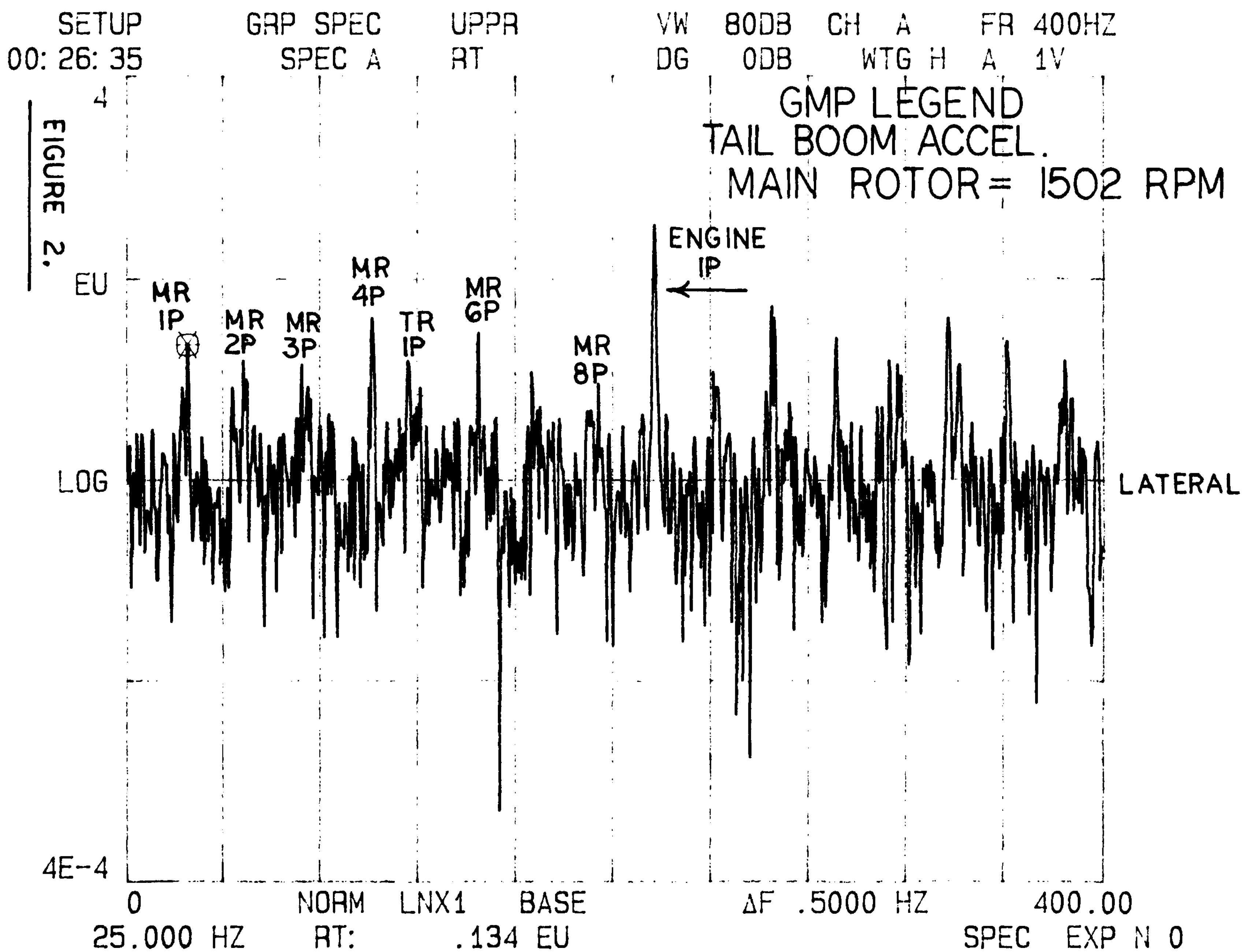
SETUP
00: 26: 35
GRP SPEC
SPEC A
UPPR
RT
VW 80DB CH A FR 400HZ
DG 0DB WTG H A 1V
GMP LEGEND
TAIL BOOM ACCEL.
MAIN ROTOR = 1502 RPM
4
EU
LOG
4E-4
MR 1P
MR 2P
MR 3P
MR 4P
TR 1P
MR 6P
MR 8P
ENGINE 1P
LATERAL
0
25.000 HZ
NORM
RT:
LNX1
.134 EU
BASE
ΔF .5000 HZ
400.00
SPEC EXP N 0

FIGURE 2.

APPENDIX E

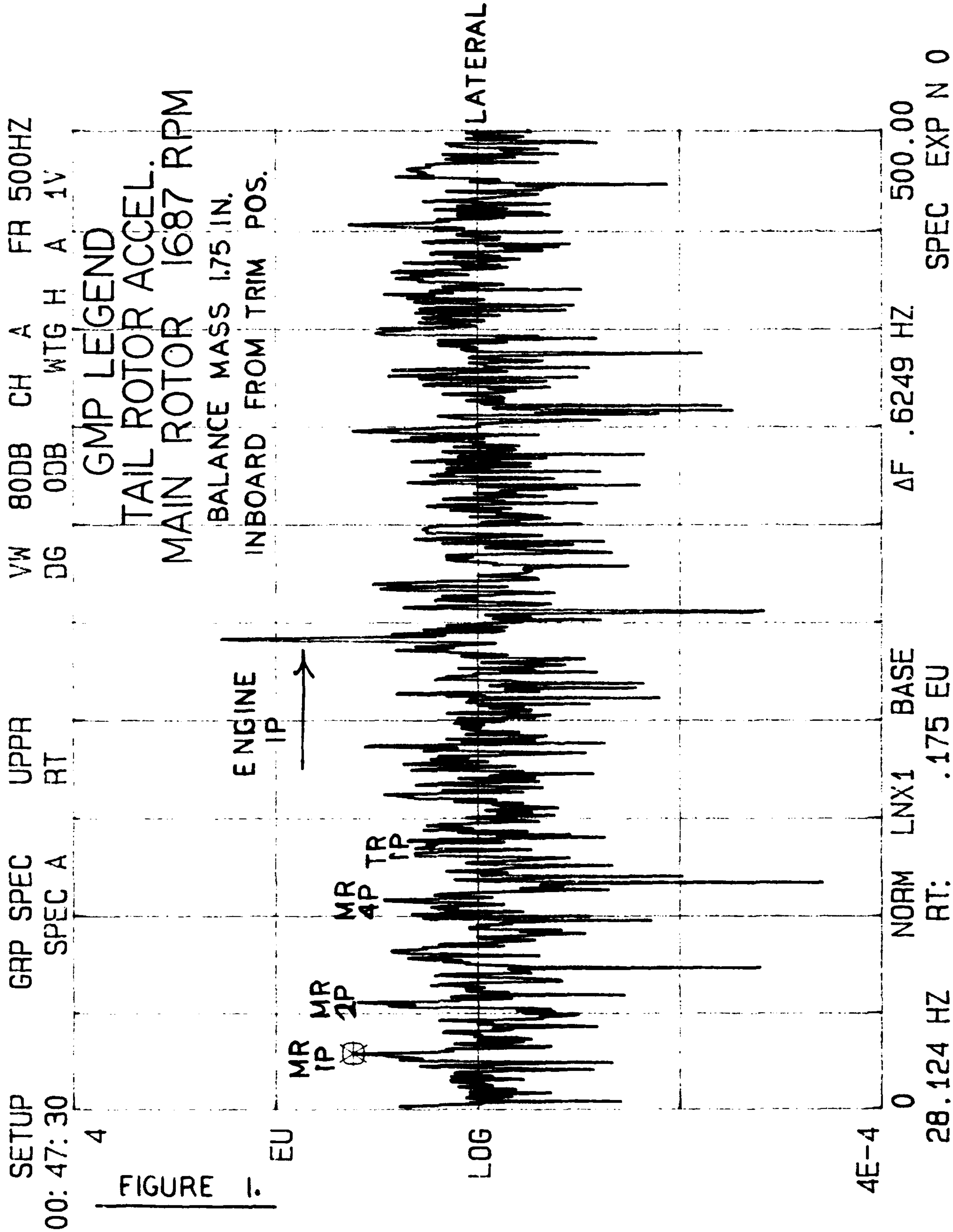

FIGURE 1.

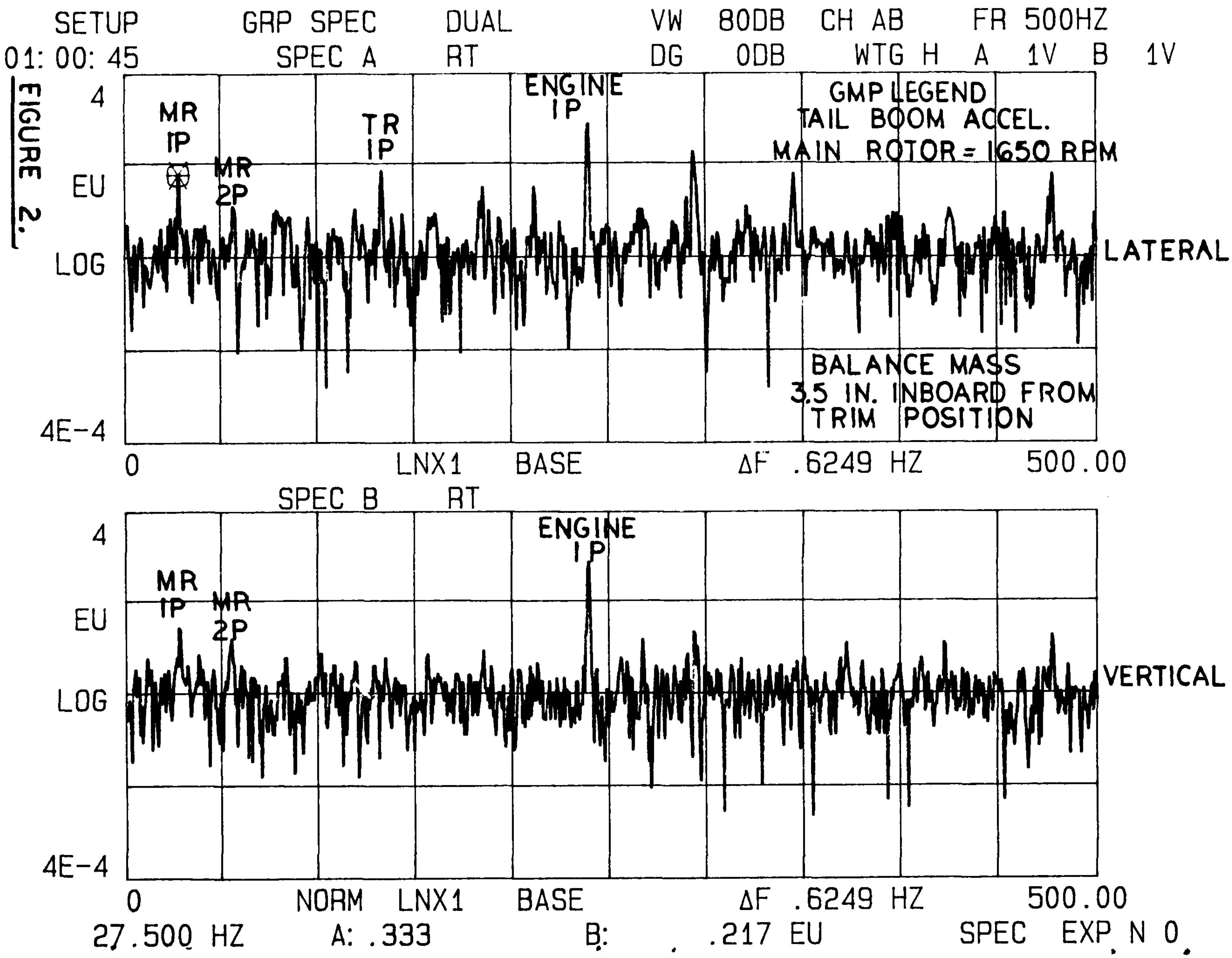
SETUP GRP SPEC DUAL VW 80DB CH AB FR 500HZ
01: 00: 45 SPEC A RT DG 0DB WTG H A 1V B 1V
4
EU
LOG
4E-4
MR
IP
MR
2P
TR
IP
ENGINE
IP
GMP LEGEND
TAIL BOOM ACCEL.
MAIN ROTOR = 1650 RPM
BALANCE MASS
3.5 IN. INBOARD FROM
TRIM POSITION
LATERAL
0 LNX1 BASE ΔF .6249 HZ 500.00
SPEC B RT
4
EU
LOG
4E-4
MR
IP
MR
2P
ENGINE
IP
VERTICAL
0 NORM LNX1 BASE ΔF .6249 HZ 500.00
27.500 HZ A: .333 B: .217 EU SPEC EXP N 0

FIGURE 2.

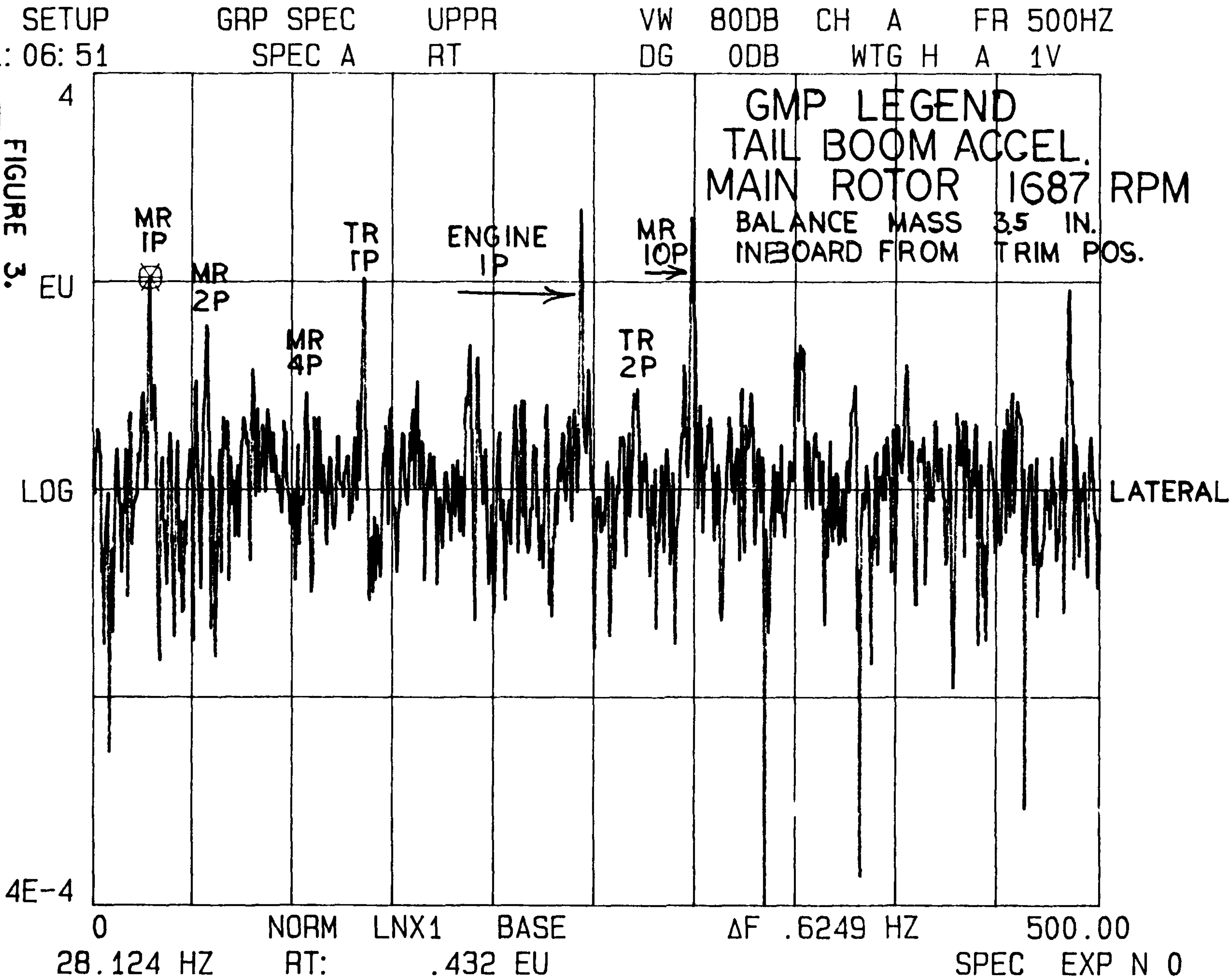
SETUP
01: 06: 51
GRP SPEC
SPEC A
UPPR
RT
VW
DG
80DB
0DB
CH A
WTG H A
FR 500HZ
1V
4
EU
LOG
4E-4
GMP LEGEND
TAIL BOOM ACCEL.
MAIN ROTOR 1687 RPM
BALANCE MASS 3.5 IN.
INBOARD FROM TRIM POS.
MR 1P
MR 2P
MR 4P
TR 1P
ENGINE 1P
TR 2P
MR 10P
LATERAL
0
28.124 HZ
NORM
RT:
LNX1
BASE
.432 EU
ΔF .6249 HZ
500.00
SPEC EXP N 0

FIGURE 3.

APPENDIX F

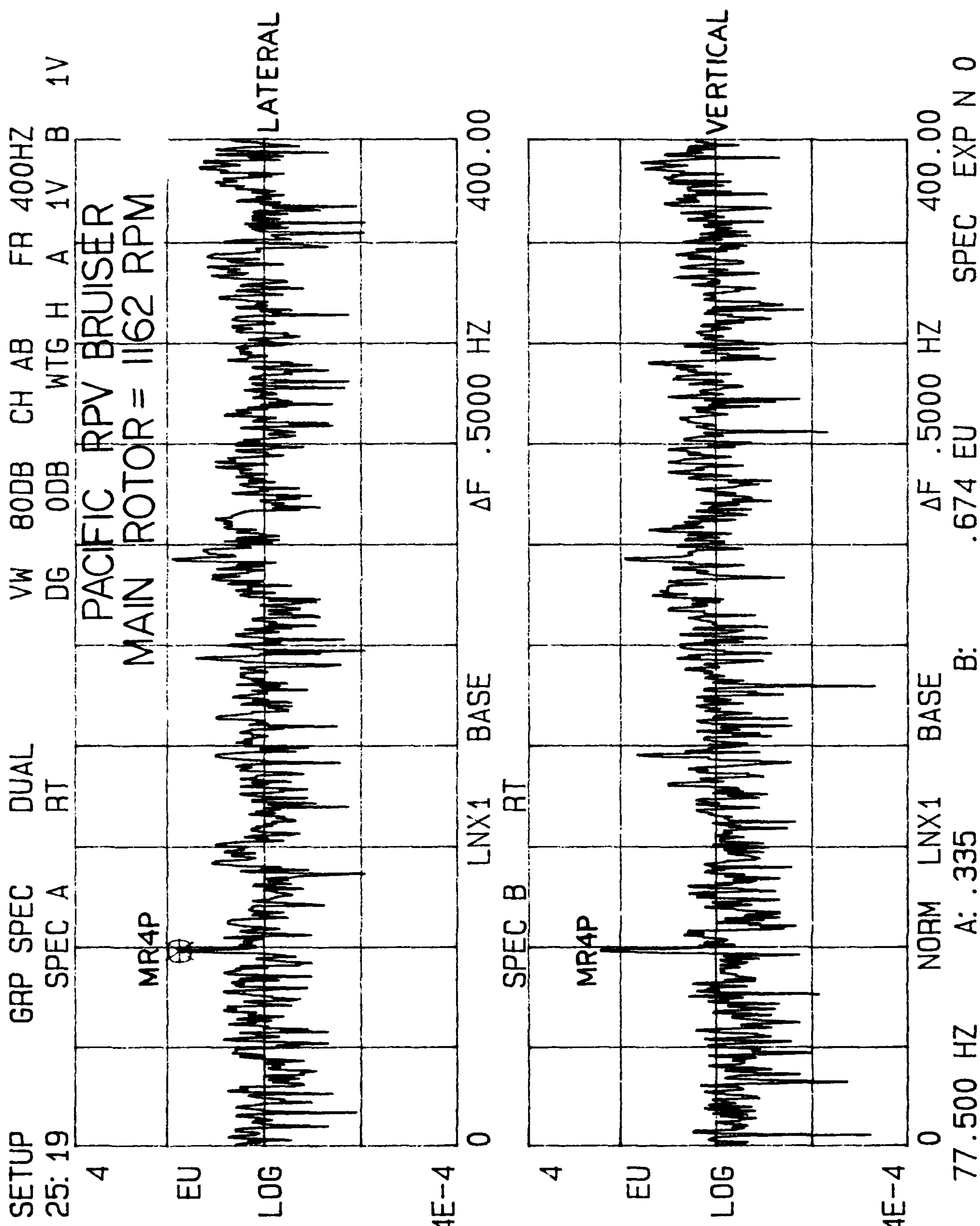

FIGURE I

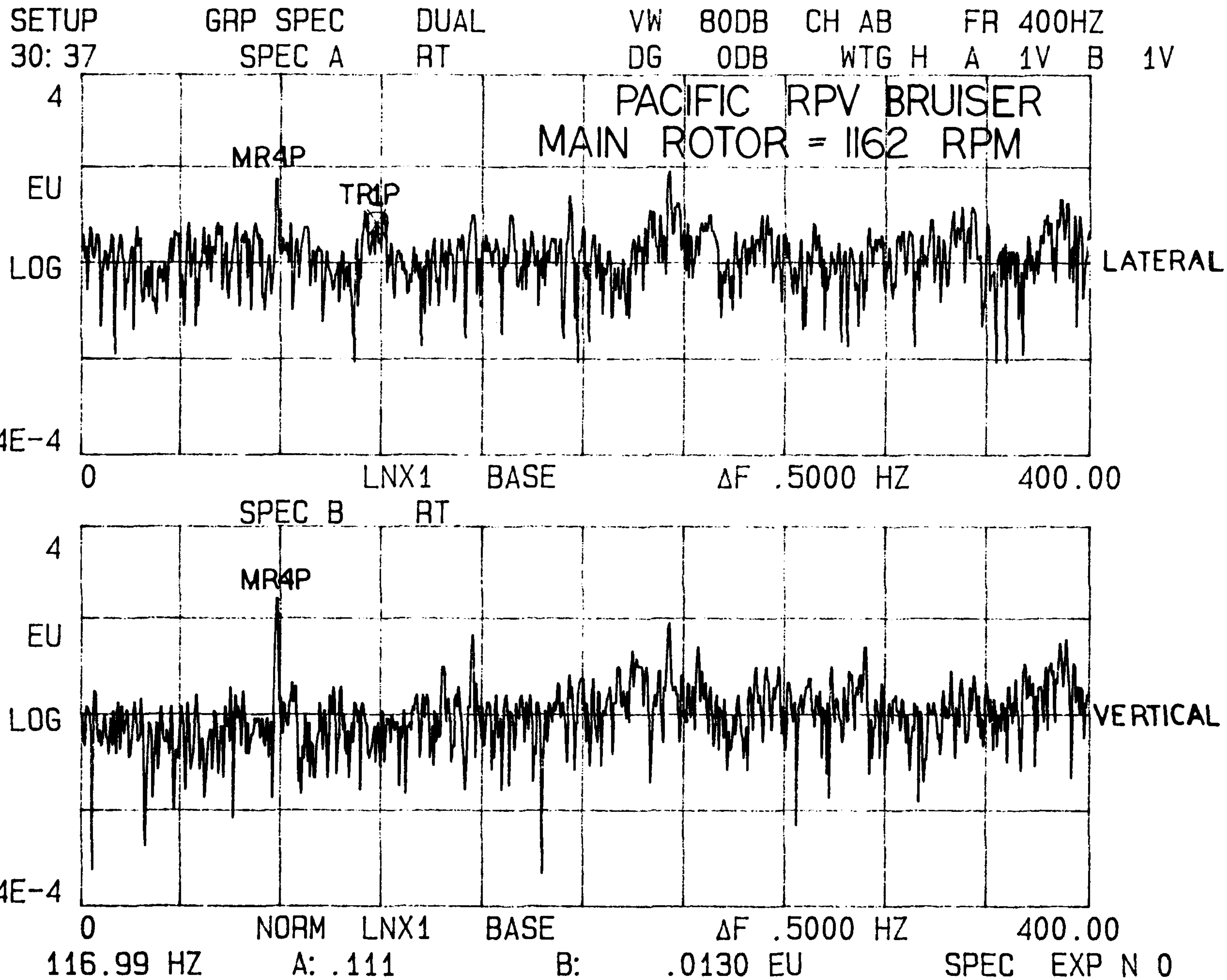
SETUP
00: 30: 37
GRP SPEC
SPEC A
DUAL
RT
VW
DG
80DB
0DB
CH AB
WTG H
FR 400HZ
A 1V B 1V
PACIFIC RPV BRUISER
MAIN ROTOR = 1162 RPM
4
EU
LOG
4E-4
MR4P
TRIP
LATERAL
0
LNX1
BASE
ΔF .5000 HZ
400.00
SPEC B
RT
4
EU
LOG
4E-4
MR4P
VERTICAL
0
NORM
LNX1
BASE
ΔF .5000 HZ
400.00
116.99 HZ
A: .111
B:
.0130 EU
SPEC EXP N 0

FIGURE 2

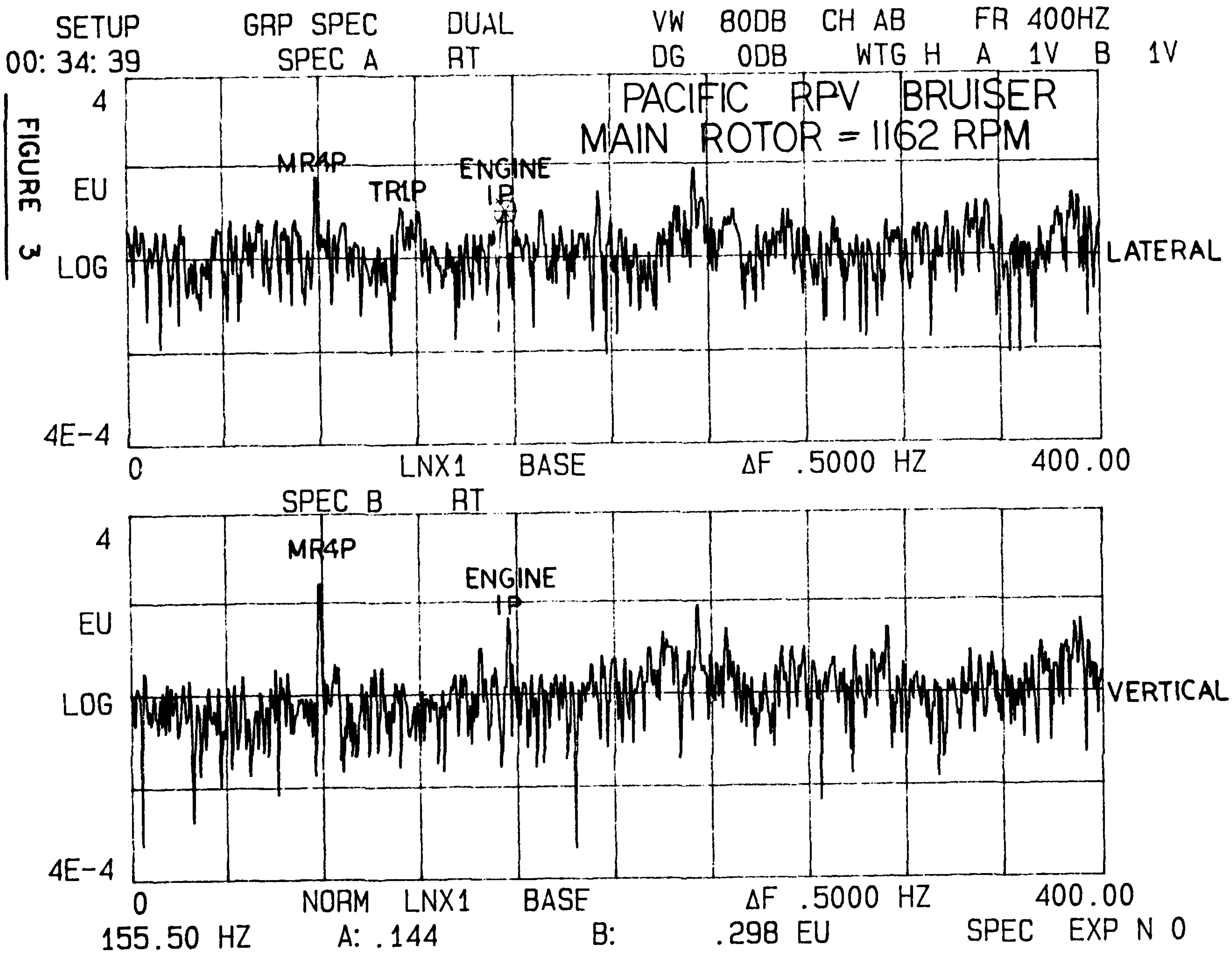
SETUP
00: 34: 39
GRP SPEC
SPEC A
DUAL
RT
VW
DG
80DB
0DB
CH AB
WTG H
FR 400HZ
A 1V B 1V
PACIFIC RPV BRUISER
MAIN ROTOR = 1162 RPM
4
EU
LOG
4E-4
MR4P
TRIP
ENGINE
1P
LATERAL
0
LNX1
BASE
ΔF .5000 HZ
400.00
SPEC B
RT
MR4P
ENGINE
1P
VERTICAL
NORM
155.50 HZ
A: .144
B:
.298 EU
SPEC
EXP N 0

FIGURE 3

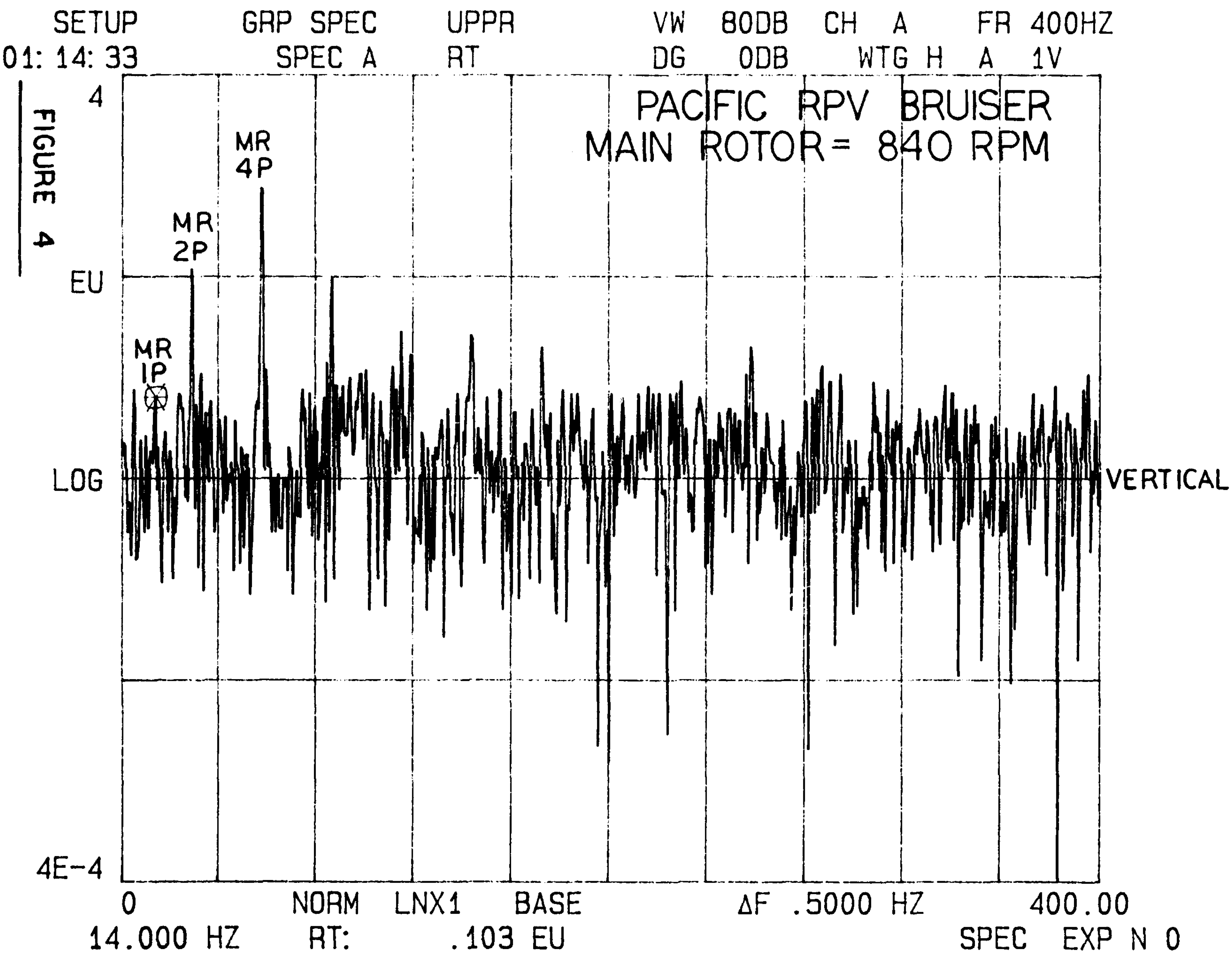
SETUP
01: 14: 33
GRP SPEC
SPEC A
UPPR
RT
VW
DG
80DB
0DB
CH A
WTG H
FR 400HZ
A 1V
PACIFIC RPV BRUISER
MAIN ROTOR = 840 RPM
4
EU
LOG
4E-4
MR
1P
MR
2P
MR
4P
VERTICAL
0
14.000 HZ
NORM
RT:
LNX1
.103 EU
BASE
ΔF .5000 HZ
400.00
SPEC EXP N 0

FIGURE 4

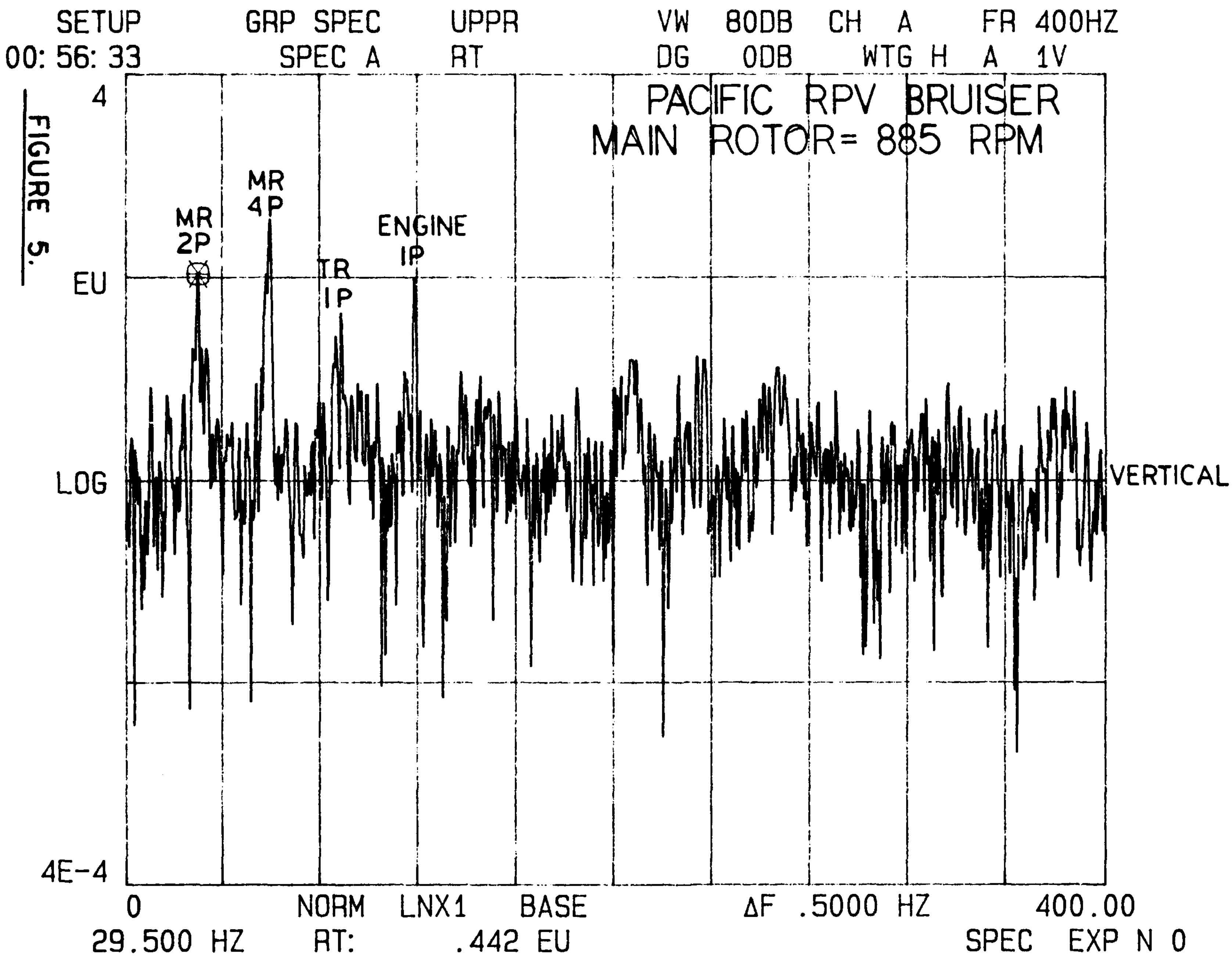
SETUP
00: 56: 33
GRP SPEC
SPEC A
UPPR
RT
VW 80DB CH A FR 400HZ
DG 0DB WTG H A 1V
PACIFIC RPV BRUISER
MAIN ROTOR= 885 RPM
4
EU
LOG
4E-4
MR
2P
MR
4P
TR
1P
ENGINE
1P
VERTICAL
0
29.500 HZ
NORM LNX1 BASE
RT: .442 EU
ΔF .5000 HZ
400.00
SPEC EXP N 0

FIGURE 5.

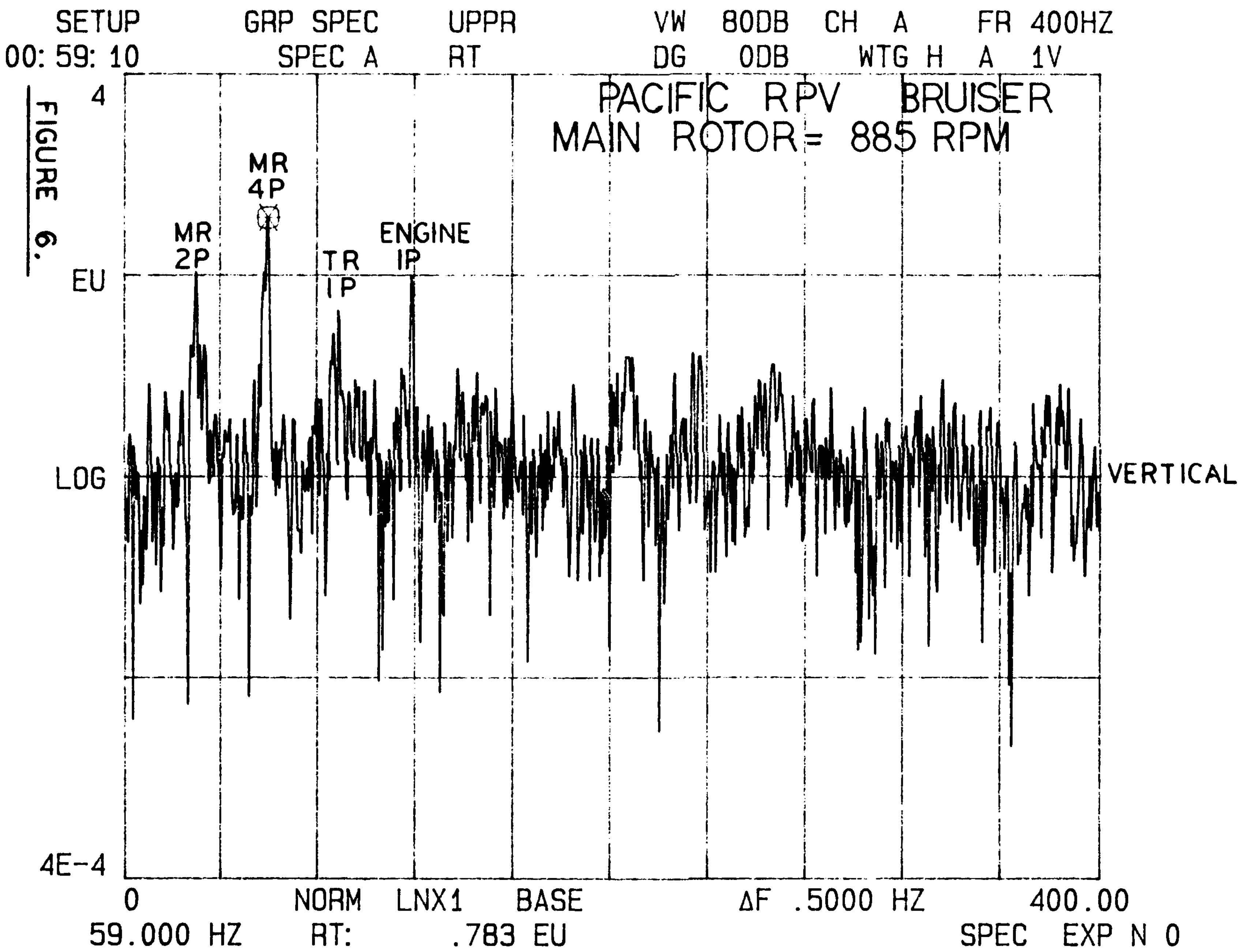
SETUP
00: 59: 10
GRP SPEC
SPEC A
UPPR
RT
VW 80DB CH A FR 400HZ
DG 0DB WTG H A 1V
PACIFIC RPV BRUISER
MAIN ROTOR = 885 RPM
4
EU
LOG
4E-4
MR
2P
MR
4P
TR
IP
ENGINE
IP
VERTICAL
0
NORM
LNX1
BASE
ΔF .5000 HZ
400.00
59.000 HZ
RT:
.783 EU
SPEC EXP N 0

FIGURE 6.

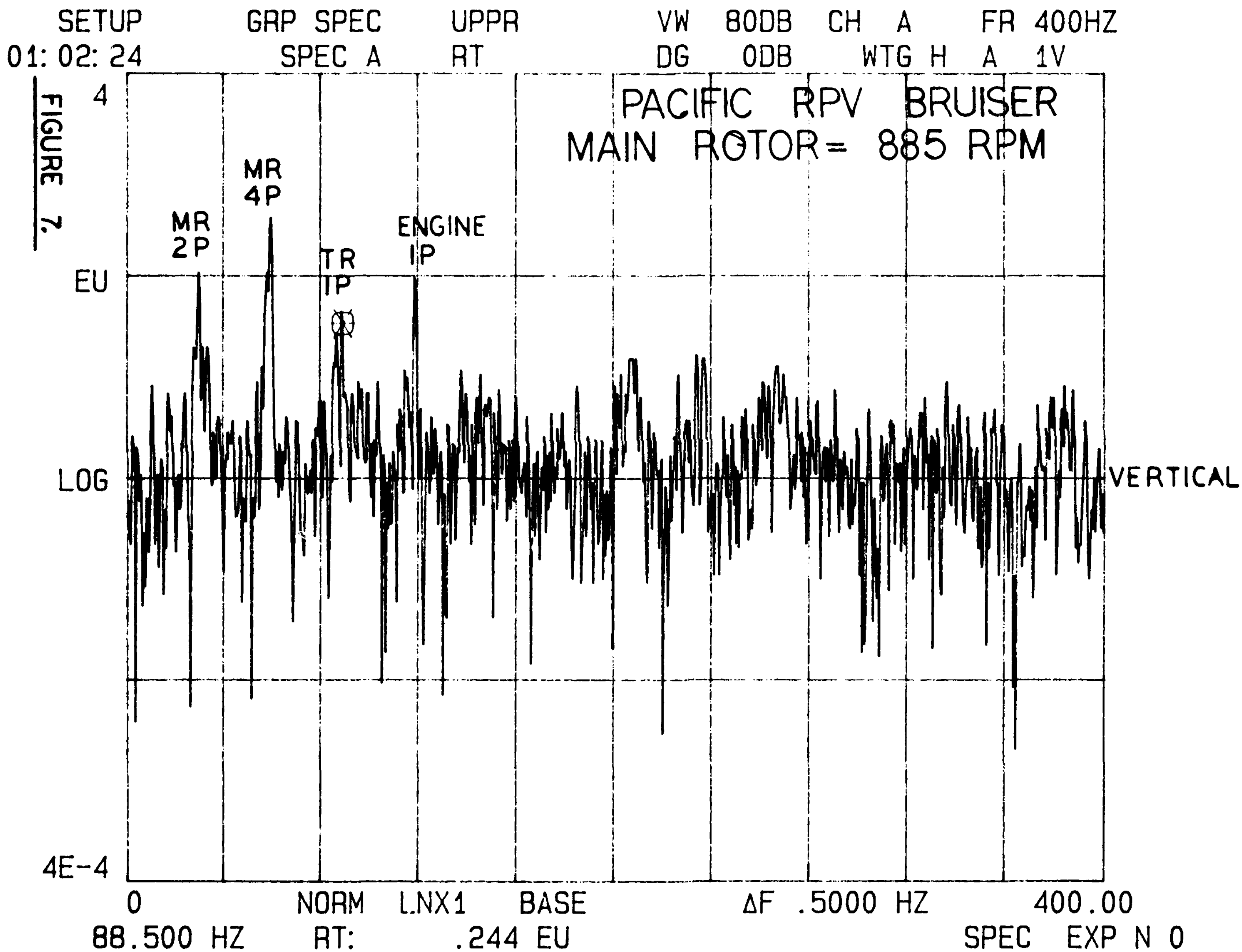
SETUP
01: 02: 24
GRP SPEC
SPEC A
UPPR
RT
VW 80DB CH A FR 400HZ
DG 0DB WTG H A 1V
PACIFIC RPV BRUISER
MAIN ROTOR= 885 RPM
4
EU
LOG
4E-4
MR
2P
MR
4P
TR
IP
ENGINE
IP
VERTICAL
0
NORM LNX1 BASE
ΔF .5000 HZ
400.00
88.500 HZ
RT: .244 EU
SPEC EXP N 0

FIGURE 7.

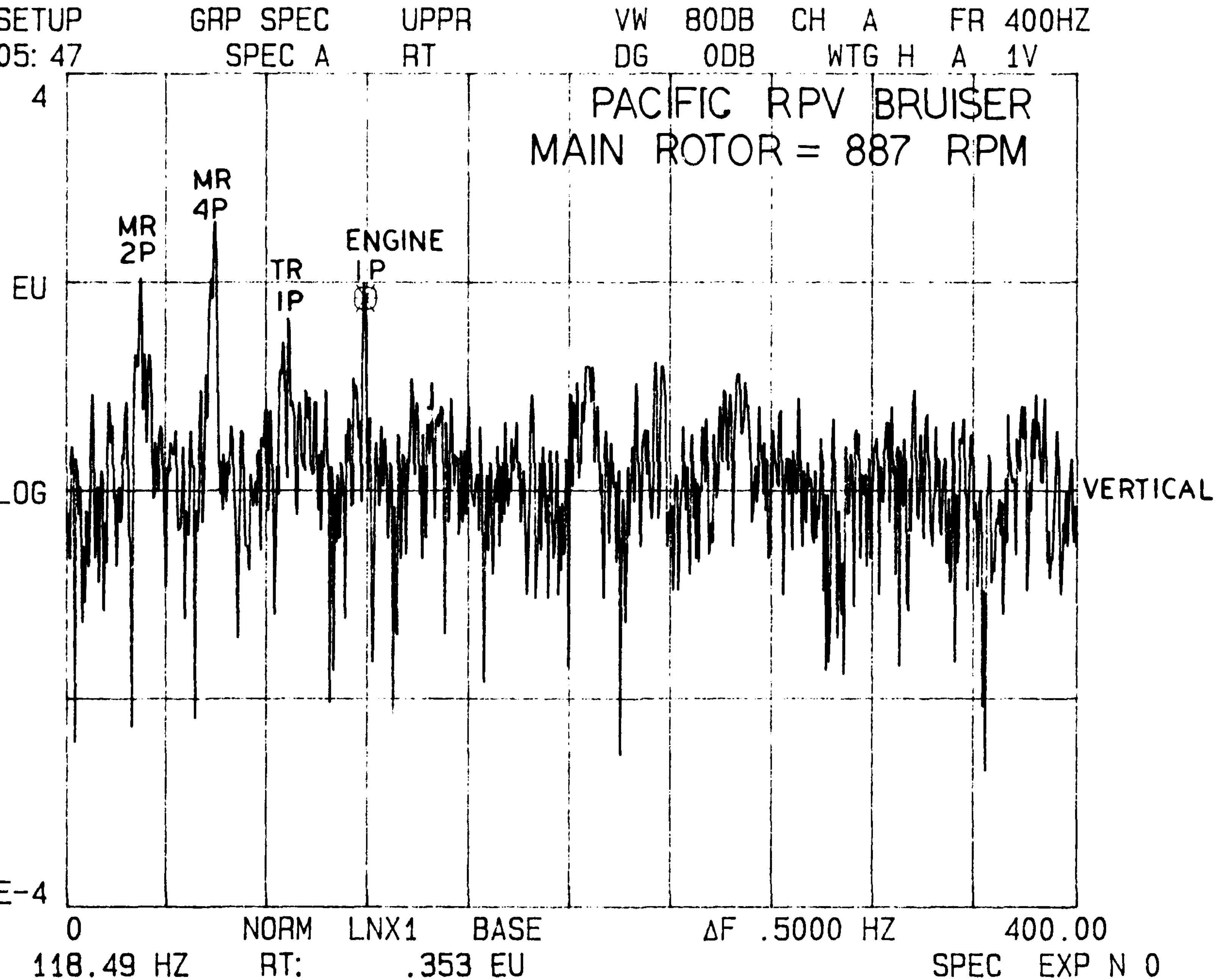
SETUP
01: 05: 47
GRP SPEC
SPEC A
UPPR
RT
VW
DG
80DB
0DB
CH A
WTG H
FR 400HZ
A 1V
PACIFIC RPV BRUISER
MAIN ROTOR = 887 RPM
4
EU
LOG
4E-4
MR
2P
MR
4P
TR
IP
ENGINE
IP
VERTICAL
0
118.49 HZ
NORM
RT:
LNX1
BASE
.353 EU
ΔF .5000 HZ
400.00
SPEC EXP N 0

FIGURE 8.

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